

# Mixed Reality Architecture

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## Abstract

This thesis develops and investigates Mixed Reality Architectures (MRA), dynamic shared architectural topologies, which span physical and virtual spaces. A theoretical framework is developed to describe the field of possible architectures. As the result of a first pilot study, this is then extended with the concept of the Mixed Reality Architectural Cell (MRACell). MRACells consist of one physical and one virtual space, linked by a two-way video and audio connection. The video of a real physical space is rendered on an MRACell, which can move within the virtual environment. A projector and screen in the real space renders an image of the virtual environment from the point of view of that MRACell. Inhabitants can move their MRACell in relation to all others within the shared virtual environment, allowing ad hoc as well as planned remote social interaction. In this sense MRACells can be described as novel architectural interfaces extending real physical space, via a shared virtual environment to link to other real spaces. An in-depth study lasting one year and involving six office-based MRACells, used video recordings, the analysis of event logs, diaries and an interview survey. This produced a series of ethnographic vignettes describing social interaction within MRA in detail. The study found that the MRA was effective at supporting remote social interaction between users. Usage patterns appeared to be motivated by awareness and communication or conversely privacy requirements. This usage maintained and strengthened social ties. Social interaction was both visible to others and part of the everyday activities at the respective office spaces. It resulted from the virtual adjacencies introduced by MRA that allowed the 'spatial' integration of remote locations. However, the virtual spatial framework making this possible, introduced new topological limitations on the number of concurrent connections that were available. Overall, it was found that the dynamic architectural topology directly affected social interaction, while social interaction itself re-shaped the topology. These findings are of direct relevance to current developments, which aim to use communications media to overcome the spatial dispersion of work groups in modern organizations. Finally, the differences in use that were observed between groups of inhabitants suggest that spatial cognition in Mixed Reality is affected both by the interface technology and by the social practices surrounding it. In response, it is suggested that in order to investigate the new generation of mixed physical and virtual technologies, cognitive science should take into account their affordances as 'virtual extensions' to both our bodies and to our environment.

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## Introduction

Architecture can be described as structuring patterns of co-presence. It influences who we encounter and who we avoid in our everyday lives. This structuring effect results from a two-way process where architecture expresses but also shapes the norms and rules of social interaction of a particular society. Outlining this process, Hillier & Hanson argue that the assemblage of architectural cells into architectural configurations can be described as a fundamentally random process, both at the level of settlement form and at the level of the spatial layout of building interiors, which is then restricted by society (Hillier and Hanson, 1984). This occurs in addition to architectural configurations being restricted by geometrical limitations as Steadman points out (Steadman, 1983). These geometrical factors can be investigated on an abstract level, which in turn can help to describe existing buildings but also in the design process for new buildings.

The resulting architectural structure has an ordering effect on the behaviour of society but also affects the adaptation of existing social rules and the generation of new ones (Hillier and Hanson, 1984). The analysis of existing architectural configurations has demonstrated that there is a strong correlation between observed spatial regularities and observed movement patterns of aggregations of individuals. This in turn affects the membership of the group of people who are co-present and co-aware of each other within a particular area (Hillier, 1996). In this sense architecture is publicly available, which makes interaction within it legible and therefore accountable (Mitchell, 1995). In physical reality, activities tend to be separated in time and space. Districts in a city or zones in a building can make these visible to the outside. Crossing from one zone to the other is also visible to others, often resulting in the location of an individual becoming a clear indicator for their activity and also status. This 'civic legibility', as Mitchell calls it, is a defining and crucial aspect of our physical environment (Mitchell, 1995).

Physical architecture can also be described as being very stable as changes to its topology are relatively slow and costly, as Brand has pointed out in his analysis of different rates of change in a selection of different building types (Brand, 1994). Change is therefore restricted to the interior of buildings in the most part, while there have been attempts to make buildings more fundamentally dynamic as seen in the architecture of Price for example (Price, 2003). More recently, Novak has then proposed the design of buildings entirely in virtual reality that could be responsive to its inhabitants (Novak, 1995). However, the architecture around us remains stable and the inflexibility associated with this stability does cause clear problems in an environment where organisational change is increasingly rapid as Penn et al argue (Penn, et al, 1999). Frequently, buildings are adapted to meet some of the above changes without the designers having a clear understanding of the possible effects.

### ***1.1 The influence of technology***

Architecture has come under the influence of a number of different technologies, whose impact on our need to be co-present has been profound. Co-presence was a pre-requisite for social interaction only until the advent of writing. With the emergence of newer communication technologies like the telephone and video conferencing the need for co-presence has been further eroded and interaction

between people who do not share the same space is now of course commonplace. As Steadman makes clear, consecutive technologies such as the point-to-point telegraph and the telephone network often co-exist for a period of time (Steadman, 1999). Indeed, the rapid growth of the Internet was only possible because hardware that was installed for other communication purposes was already in place (Steadman, 1999). These various communication technologies then had a clear effect on urban structure. Certain functions such as legal and administrative services became concentrated in urban centres, while other functions such as manufacturing, where moved to the periphery. Steadman argues that these two processes continued in parallel throughout the 20<sup>th</sup> century (Steadman, 1999). Castells adds that these developments are part of the development of the 'network society', a network of digital networks built on the basis of existing values, interests and projects. For an understanding of its properties, global and local aspects need to be considered (Castells, 2004). Within this new paradigm, connection to the network is critical, while it can not guarantee access, and as good connections are not available everywhere, simply because the hardware might not be present, inclusion in the network society often still depends on physical location.

Mitchell in turn provides another perspective by identifying a general shift of human activities away from physical space into the digital domain. Digital libraries, online malls and online banks are all examples of institutions that not long ago were associated with physical buildings and would have required physical travel to a particular place for any transaction with them (Mitchell, 1995). The author does not suggest that cities will disappear in the process, but rather that their structure will fundamentally change, since access to services becomes independent from location. These new architectures then afford dynamic, near instant access to non-adjacent parts in their topology and Virilio argues that the distinction between near and far becomes irrelevant here. Effectively, the spaces 'travelled across' are lost and become invisible. They are compressed and social interaction across two spaces is de-spatialised (Virilio, 1997). Entirely electronic environments such as chat rooms for example exacerbate this process. Here location can not be associated with activity anymore and 'civic legibility' is lost (Mitchell, 1995). In addition, everyone can take on multiple personalities. In response, Benedikt argues for such environments to adhere to some fundamental

properties derived from physical reality to make them intelligible by its users (Benedikt, 1991). Mitchell points out that the overall structures of virtual environments often already resemble that of physical ones (Mitchell, 1995). In those cases a city metaphor is employed by the designers to structure activities of inhabitants. This includes public and private areas and the social norms and customs that go along with these.

## *1.2 Spatial approaches*

The technology that drives digital environments that are based on spatial metaphors is that of Collaborative Virtual Environments (CVE) (Greenhalgh, 1999). CVEs present people with an interface to a shared three-dimensional computer generated space. This interface provides means for navigation through this space and communication with others. People are typically represented with figures (avatars), and this embodiment makes actions and interactions by any particular person available within the CVE. This can in principle re-introduce the possibility for chance encounters even between people who are physically remote to each other. Numerous such environments have been developed and tested for entertainment and collaboration purposes. While this research mostly focused on interactions within the virtual environment, it also has become evident that the local physical situation of any of its participants will have to be considered for the understanding of such systems. Bowers et al point out that ongoing activities in physical and virtual spaces clearly influence each other and that it must be possible to display those on both sides of the interface (Bowers, et al, 1996).

Mixed Reality is a much more recent technique for social interaction and communication that aims to integrate virtual and physical spaces much more tightly. Mixed Reality has the potential to support social interaction that spans physical and virtual spaces much better since it attempts to embed people physically remote from each other within the same spatial framework. There are a number of approaches to Mixed Reality typically defined by the relationship they conceptually impose on combinations of the physical and virtual (Milgram and Kishino, 1994). One such approach, Augmented Reality, places more emphasis on the physical, as it allows information from virtual space to be accessed from within physical space. For example, see-through head mounted displays are used to overlay the virtual on to the physical background or virtual information can be

projected out into physical space (Feiner, et al, 1997). In contrast, Augmented Virtuality emphasises the virtual, as it augments virtual space with aspects from physical space. This can be achieved for example by live video feeds from a physical camera (Reynard, et al, 1998). One particular approach to Mixed Reality which is conceptually seen as treating physical and virtual spaces equally is that of the Mixed Reality Boundary (MRB) (Koleva, et al, 1999). MRBs establish a 'window' between physical space and virtual space (embedded within a CVE) with the aim of simulating co-presence between physically remote people. In this way, the MRB technology combines aspects of Augmented Reality and Augmented Virtuality. Virtual space is made available over the network via a variety of interfaces as a CVE. Each physical space that joins this virtual space via an MRB is made available to everyone in the shared virtual space as a live video view (see section 2.3.1.c for a full description).

### ***1.3 Mixed Reality Architecture***

In summary it can be said that architecture, while having a clear structuring effect on co-presence as the pre-condition for social interaction, is very static and inflexible. Although it provides the spatial framework for social interaction it appears somewhat at odds with a very flexible and rapidly changing society living within it. This flexibility, especially in terms of crossing spatial boundaries is provided by communication technologies in numerous different forms that have their own structuring effects on social interaction. However this social interaction remains hidden from view and as a result there can be no 'civic legibility' of social interactions within the most commonly used telecommunication technologies.

The aim of this research is therefore to investigate ways of combining the spatial configurational aspects of architecture with the dynamic aspects of communication technologies and to study the effects on social interaction within such a combination. The research focuses on two very much interrelated questions: How can architecture be made more dynamic to be able to respond to organisational change? How can social interaction across multiple physical spaces as supported by communication technologies be made more like social interaction that occurs within the framework of physical buildings? To address these questions, this thesis proposes and investigates the concept of Mixed Reality

Architecture (MRA): an approach to Mixed Reality with a distinctly architectural perspective. It involves linking and overlaying multiple physical and virtual spaces in a dynamic way in support of social interaction of people who are not physically co-present.

To be able to deal with this main research problem, a number of additional supporting questions will need to be addressed. Firstly, Mixed Reality Architecture will clearly require a careful grounding in previous work. Based on this review it would then be beneficial to attempt to theoretically frame the likely properties of this new architectural concept. This, it is argued here, will be useful as a resource for the experimental implementation work that is to follow but also more generally for the development of other Mixed Reality approaches. Secondly, architecture is a relatively stable phenomenon which is affected by the society inhabiting it and in turn affects this society itself. This process takes place over extended periods of time. It is therefore only reasonable to expect that for an understanding of the two-way process between society and architecture as it evolves within MRA, extended periods of study are required that in turn should allow room for changes to the particular implementation under investigation. Thirdly, as has been briefly pointed out above, the inherent flexibility of modern organisations is frequently at odds with the stability that buildings provide, and it seems that for this reason, this domain could benefit most from a more flexible architecture. Of course, within organisational settings, there are numerous types of activities that might be supported with the new architectural approach introduced here. Since the overall aim of this research is to investigate the relationship between dynamic architecture and the social interaction taking place within it, it will be critical to identify the right type of activity within the right type of organisation that might maximise the scope for findings in this area. Finally, once concrete implementations of MRA are in place, a thorough investigation of its properties can follow, which can reflect on the interplay these properties and the social interaction that might emerge within it have.

## *1.4 Structure of this thesis*

Following this introductory chapter, introducing the reader to the research into MRA, there are 9 main chapters. These are followed by a conclusion chapter summarising what has been achieved and providing an outlook on possible fu-



ture work. The following is a brief overview of the material covered in each of the main chapters:

**Chapter 2** provides the literature to ground this research in previous work. This review is presented in three main parts. Firstly, different perspectives on architecture in the age of communication technologies are outlined with a particular regard for issues related to co-presence and social interaction. This is followed by an analysis of the different rates of change possible within physical architecture. Its overall inflexibility seems to conflict with the very dynamic society that constructs and inhabits it. Secondly, the extent to which communication technologies have already influenced architecture and the urban fabric is discussed. This is then followed by a detailed review of a selection of remote communication technologies. The research for MRA is inherently cross-disciplinary and the literature reviewed here spans the two main fields of Architecture and Computer Science, while material from other fields has been included where relevant.

The literature presented in this review provides the motivation and background for the investigation of a flexible architecture consisting of linked physical and virtual spaces, which embeds its inhabitants in a shared spatial framework, with a particular regard for the type of social interaction occurring within it. This Mixed Reality Architecture is a novel architectural concept, which has not been investigated previously in this form, but promises to bring together the flexibility of telecommunication technologies and the legible spatial framework for social interaction that architecture provides.

**Chapter 3** introduces the framework of Mixed Reality Architecture. Reviewing the literature in the previous chapter clearly showed that although researchers have explored many aspects of MRA separately, no framework exists that could describe it in its entirety. Therefore, the development of such a framework seemed essential for the future extension and development of MRA. The framework describes the field of possible architectures that emerges when physical and virtual spaces are combined. The framework has been divided into three categories. These are concerned with the qualities of physical and virtual three-dimensional spaces, the qualities of links between a combination of the two and the qualities of the resulting architectures.

The framework of Mixed Reality Architecture is first applied to accessing an online 3D virtual environment via a mobile computing device such as a mobile phone. It is then also used to describe the two different Mixed Reality Architectures developed as part of this research. This demonstrates that it is a useful resource for the development of Mixed Reality systems in general but more specifically for architecture developed in this area.

**Chapter 4** provides details of the methodology employed for the research presented in this thesis. Further developing the concept of MRA, as motivated through the literature review and as theoretically outlined in the framework chapter, required the design, construction and long-term evaluation of MRA in an everyday setting. Although it was possible to derive certain design decisions on precedents partly based on existing experience with related technologies and set-ups, it was also clear that many issues would only come to light when actually inhabiting MRA. To capture these it was decided to adopt an iterative design and prototyping process as the main method of enquiry using early and continuous evaluation. Two major prototypes of MRA were developed within an everyday office environment. In addition, the second prototype was also iteratively refined through a series of smaller prototyping steps. This process had to reflect currently available technologies and the work practices at the given settings. Prototyping as a process is introduced, reflecting back on the situated nature of the study proposed here and the possible participants in the study. This is followed by an overview of the evaluation methods that were employed to support the prototyping process as well as the final evaluation of MRA. These are situated observational studies, interviews, sketch maps and the replaying of virtual environments.

This overall methodology for the study of MRA has been motivated by the novelty of the concept, the lack of practice around that concept, the distributedness and the situatedness of the prototypes. A prototypical approach to development combined with a mainly qualitative evaluation process is arguably the only method that can drive the design, construction and evaluation of Mixed Reality at this early stage of its development.

**Chapter 5** introduces the design, implementation and evaluation of the initial pilot study in the prototyping cycle of MRA. For this study, a prototype MRA was set up at the Mixed Reality Lab (MRL) at Nottingham University that provided

an environment for distributed presentations given by local and remote speakers to local and remote audiences. It linked four physical spaces across one virtual space. The study took the form of a staged event and focussed on a number of key issues with the aim to start evaluating the concept of MRA especially in terms of its dynamic properties and its influence on co-presence between people not physically co-located. It was also concerned with gaining a better understanding of giving presentations to distributed audiences, where speakers and audiences communicate over a computer network instead of physically travelling to meet face-to-face.

In contrast to previous work that has addressed this application area, here an approach is taken that combines a physical spatial framework for local participants and a virtual spatial framework for remote participants into a shared MRA embedding local and remote speakers as well as audiences. It is this virtual spatial framework that is shown to be the key for establishing awareness between the participants in this study, who are distributed across a number of physical spaces. This awareness in turn is the basis for the types of social interaction exhibited during the two distributed presentations. Finally, the type of interface between physical and virtual spaces has a clear role to play. Only larger-scale, public Mixed Reality Links are demonstrated to be effective in creating a legible Mixed Reality architectural topology.

**Chapter 6** details the design considerations for the second major phase of prototyping of MRA. This second study was developed in a different application domain in support of everyday awareness and social interaction in the MRL. This required a different approach from the previous study, although certain elements were taken forward. As a result the general framework of MRA presented in chapter 3 was expanded here with the key concept of Mixed Reality Architectural Cells (MRACell). Taking inspiration from the properties of physical architectural cells, each MRACell combines one physical and one virtual architectural cell to simulate co-presence between people present within them, whether they are local or remote in relation to each other. MRACells are the basic building blocks of MRA. They are virtually dynamic, allowing inhabitants of MRA to establish different architectural topologies according to their requirements. MRACells are embedded simultaneously in one physical topology as well as one virtual topology and provide their inhabitants with full control over access from both of

these, in a very similar way to physical architectural cells. Two different designs for MRACells are introduced, their possible physical locations discussed, before their function as inhabitant representation and the representation of MRA as a whole is outlined.

MRACells can be described as novel architectural interfaces with certain properties that have not been available in architecture before. Firstly, spatial relationships between multiple MRACells are not pre-specified in design, but are entirely dependent on the interaction by inhabitants. In contrast, in physical architecture the topology is pre-specified, relatively fixed and costly to adapt. Secondly, whereas physical architecture structures social interaction between co-located people, MRACells enable and control social interaction within a legible architectural framework, between people who are remote to each other. It is argued that this architectural approach to designing the interface between physical and virtual spaces is also directly applicable to the design of other telecommunication technologies.

**Chapter 7** presents a base line description of the existing social networks in the various settings under investigation before describing the initial two prototyping cycles of the construction phase of MRA. The social networks are such that they stretch across local and remote physical spaces. As all sites chosen for MRA are research settings, collaborations are not confined to the local environment and many work colleagues are not co-located. This provided an ideal test bed for MRA. The first phase of the prototyping cycle was an initial pilot study with three MRACells conducted during October 2003. The second phase was a follow up study with four MRACells that was conducted between January and June 2004. The actual implementation of MRA including all six MRACells that were set up is described before detailing instructions given to inhabitants and the changes to MRA that were introduced right at the beginning. The two phases of the development took place within the day-to-day activities of the MRL, a working and very active research environment.

The overall aim of the evaluation of the two prototypes was to better understand issues in the design, construction and use of MRA, and this required an evaluation of the suitability of the implementations and the concepts that led to its design but also the uncovering of additional unforeseen issues. These earlier findings were then fed back into the development cycle, resulting in a robust and

useable implementation that could be evaluated longer term with MRACells introduced locally but also at other sites.

**Chapter 8** presents the data collected during the evaluation of the final prototype, which took place between July and October 2004. For this final phase of the study of MRA two methods were used. The main method was an observational study. This was supported by recording and replaying virtual environments. The combination of these two allowed the production of vignettes, combinations of transcriptions, video still images and maps generated from events that were recorded on video tape. These described a selected group of interactions in very fine detail with the aim of abstracting larger issues from these. The analysis in general was also supplemented with more informal feedback from inhabitants and information drawn from the diaries that some inhabitants kept of key events. Additionally, the data logs recorded within the virtual environment allowed quantitative analysis of patterns of use over longer periods than the observational study allowed.

**Chapter 9** discusses the findings presented in chapter 8 from two very much interrelated perspectives before considering wider implications for environmental cognition in general. Firstly, the architectural implications of this work are outlined. MRA is a novel architectural concept and it can be described in terms of its configurational properties and the impact of those on social interaction. Its topology consisting of physical and virtual spaces allows geometrical architectural limitations in physical space to be overcome. Virtual spatial adjacencies between local and remote spaces result in changes to the topology, which are then shown to influence movement and social interaction. At the same time, as social interaction is embedded within a virtual spatial framework, new limits on adjacencies are the result, which, it is argued, can only be completely overcome once telecommunication reverts to providing no internal spatial framework. The Mixed Reality Architectural Cell, the novel architectural interface developed for this research, is itself spatially dynamic. It enables and controls social interaction between people who are not physically co-present. No spatial relationships are pre-defined between multiple MRACells, making the resulting architectural configuration entirely dependent on the interaction of its inhabitants. The second part of the discussion chapter provides a detailed description of life within MRA. This is discussed in terms of how it is affected by the architectural topology and

in terms of how it affects the topology itself. This is in effect a post-occupancy evaluation of MRA as designed and built during this research. The focus here is not on another iteration in the prototyping cycle, but instead the aim is to provide an in-depth understanding of what it means to inhabit MRA. It is shown that the quality of the interface but also the patterns of use around an interface give different groups of inhabitants very different sets of experiences in MRA. It is also argued that the MRA approach supports social interaction well and that this interaction is very much occasioned. In summary, MRA can be said to support the existing social network of connected inhabitants very well, and that it can help to extend it under certain circumstances. Finally, the observed differences in the use of the MRA interface prompted the analysis of the cognition of general Mixed Reality space in view of the relatively recent 'embodied-embedded' approach to environmental cognition. Mixed Reality can be said to extend our bodies and environments into virtual space and, in the case of MRA, also into remote physical space. In that sense the scope of our cognition is clearly also extended. With the background of the ever more widespread use of Mixed Reality type technologies, it is then argued that the field of environmental cognition should consider digital extensions to body and environment as a permanent feature within its explanatory frame.

In summary, the design, construction and evaluation of MRA shows how a dynamic architectural topology, which spans virtual and physical spaces relates to co-presence and social interaction occurring within it. For physical architecture, it has been argued previously that social norms and rules determine spatial topologies, which in turn influence patterns of co-presence, with direct effect on social interaction. Within Mixed Reality Architecture, as this research demonstrates, this relationship is much more direct and rapid. To establish co-presence for social interaction, the architectural topology has to be re-configured in such a way that brings different architectural spaces close enough together. In turn, the resulting architectural topology, as established by its inhabitants on the fly, enables or prevents social interaction that might follow. This fundamental, direct and immediate dependency between architectural topology and social interaction is a key result of this research.



## Architecture\\Telecommunication

Two seemingly disparate fields, architecture and telecommunication, will be discussed in this chapter in terms of their respective influence on co-presence, which is in turn the prerequisite for interpersonal awareness and therefore social interaction. Architecture and telecommunication both clearly influence co-presence, but they do this in very different contexts. Architecture structures actual physical co-presence, while telecommunication simulates co-presence at a distance as a substitution for physical co-presence.

Mitchell concisely categorises the different contexts of social interaction into local and remote as well as synchronous and asynchronous (Mitchell, 1999). *Local synchronous* social interaction requires transportation to bring people together and coordination to make sure that they are in the same place at the same time. This

incurs comparatively high costs and demands the participants' full attention, but it is of course the most direct and personal contact possible. Local synchronous social interaction takes place within and is shaped by the architectural space as will be shown below. Mitchell adds that only literate societies have access to *local asynchronous* communication (Mitchell, 1999). This eliminates the need to coordinate affairs but still requires at least one person to travel to the other person's place and for example leave a note on an office door. Of course, the invention of writing also allowed letters to be sent, an example of *remote asynchronous* social interaction. Here transportation and coordination are no longer necessary as social interaction is displaced in time and space. Interaction has increased in speed with the invention of the telegraph, the telex and the fax machine. With the establishment of digital networks, it has become widespread in the form of email, the 'most fundamental effect of the digital revolution' according to Mitchell (Mitchell, 1999). Finally, telecommunication typically refers to *remote synchronous* communication made possible through technologies like the telephone and videophone. Transportation is no longer required but coordination still is. Social interaction is displaced in space but not in time.

The research presented here is concerned with the first and the last of the above categories and this is reflected in the following review. Firstly, architecture is discussed as the framework for physical co-presence, which in turn is the prerequisite for local synchronous interaction. Secondly, an overview is provided of telecommunication as the technology that allows people to simulate co-presence at a distance, and of how telecommunication has influenced architecture and urban space. Finally, this review details a selection of telecommunication technologies that are directly relevant in this context.

## ***2.1 Architectural topologies***

Architectural topologies are fundamentally based on the process of segmenting and re-assembling portions of physical space. Simmel considers some basic premises and the relationship between mental and spatial separations and re-connections by discussing a variety of physical phenomena (Simmel, 1909). First the author turns to the meaning of paths, which he describes as the first manifest connection of two points in space created by people, in effect physically expressing the mental connection of two spaces. Bridges are described as an extension of



paths as they connect two spatial regions that are otherwise separated in nature like the two banks of a river, for example. However, Simmel argues that we would not perceive the two river banks as separate had we not previously connected them mentally. Simmel writes:

*"Only for us are the banks of a river not just apart but 'separated'; if we did not first connect them in our practical thoughts, in our needs and in our fantasy, then the concept of separation would have no meaning."* (Simmel, 1909)

Finally, doors show even more strongly how the acts of separation and connection are intertwined. To be able to construct a door, in effect linking two spaces, it is first necessary to separate a portion of physical space with a boundary. Without this separation, linking two spaces is meaningless and it becomes clear that this process of separation and subsequent linking is part of the same human activity. More importantly though, the creation of bridges, boundaries and doors not only has practical goals and effects but also visualises or makes concrete the mental act of spatial connection and separation.

One core aspect of Simmel's analysis is the separation of a volume of space from its surrounding space by way of enclosing it. In fact, this is a position very commonly adopted by architects when describing the relationship of architecture to physical space (Hillier, 1996). At this point it is worth stepping back a little to put this position into context. The following is a very brief overview of three key points of departure that architects and architectural theorists have put forward when discussing architectural space. This is drawn from two pieces of work: *Space in Architecture* by Cornelis van de Ven (van de Ven) and *Words and Buildings* by Adrian Forty (Forty, 2000).

### **Architecture as enclosure**

Semper can be credited with the introduction of the concept of space to modern architecture (van de Ven, 1987). His *Stillehre* of 1851 introduced the three 'moments' of *Symmetry*, *Proportion* and *Direction*, corresponding to the three spatial extensions of width, height and depth of natural form. The space-enclosing function of human artefacts became a major concern for the first time with matter being only secondary. Referring back to Newtonian physics, space is seen as absolute, abstract and infinite. Architecture divides this space into sections that provide an enclosure and make it measurable. As such space is seen as a mere container, independent of material objects. Forty points out that Semper's influ-

ence reached to the 'proto-modernists' Berlage and Loos and via them to the main protagonists of modern architecture (Forty, 2000).

*"If, for practical purposes, we separate, limit and bring into a human scale, a part of unlimited space, it is a piece of space brought to life as a reality. In this way a special segment of space has been absorbed into our human system. (...) Truly, the idea of general space, which we accept as existing, manifests itself only as a continuation of such a piece of reality which was produced through limitation."* (Gerrit Rietveld as quoted in (van de Ven, 1987) @ 32)

### **Movement through a spatial continuum**

A second approach, which is far less easily applied, was inspired by Leibniz' relative space and Einstein's space-time. In its application to architecture it can be summarised as emphasizing space as a continuum and movement through this spatial continuum. Moholy-Nagy, one of the main theorists of the Bauhaus, synthesised a number of previous conceptions, rejecting space as enclosure or space equating volume. Instead, inspired by Einstein's theory of relativity and the introduction of four-dimensional space-time to the arts by the Cubists, he saw space as much more fluid, running through a building and made visible by it, connecting inside with outside.

*"Boundaries become fluid, space is conceived as flowing ... Openings and boundaries, perforations and moving surfaces, carry the periphery to the center, and push the center outward."* (Lazlo Moholy-Nagy as quoted in (Forty, 2000) @ 267)

Moholy-Nagy describes space as effectively resulting from motion, changed by the observer's movement through it. Gropius in turn translated this into an architecture using 'large areas of glass, evoking transparency, stimulating the perception of an illusion of a floating continuity of space' (van de Ven, 1987). The architect therefore concentrated on the most common translation of the concept of space-time to art and architecture: the idea that the element of time would be introduced through the movement of observers through space. Moholy-Nagy went much further by suggesting the movement of architectural elements themselves, when he considered the mobile architecture of cars, trains and planes in *Vision in Motion* (Moholy-Nagy, 1947) (as referenced in (van de Ven, 1987)).

### **Place**

In a sense as reaction to the above developments a re-evaluation of spatial concepts took place in an 'attempt to bring to a halt the formal and alienating spatial

supremacy in Functionalist architecture since the 1920s' (van de Ven, 1987). The concept of place or locale, inspired ultimately by Aristotle, gained larger influence in the 1950s. Forty emphasises the influence of Heidegger who contrasted empty, mathematical and measurable space to *place*, which was occupied and defined by objects as well as people (Forty, 2000). This goes in parallel with the notion that more abstract spatial theories regarding the infiniteness of the universe or its dimensionality are irrelevant to everyday human experience. Lefebvre introduces the concept of *social space*, a product of society. He argued that social space is at once 'perceived (through the social relations of everyday life), conceived (by thought), and lived (as bodily experience)' (Forty, 2000) and he lamented the fact that these notions had been reduced and abstracted by modernism. Rather than treating it as a neutral, empty space that can be shaped, he prompts architects to understand space as already 'occupied' by society and to understand architecture as one social practice among others that shape the space of a society.

All three approaches to the discussion of the spatial nature of architecture draw their inspiration from theories other than architecture itself. Hillier points out that these approaches as well as other architectural theories drawing from different disciplines, while often leading to new directions in architectural design, are too often normative before they are analytical (Hillier, 1996). They propose or sometimes even prescribe architectural design solutions that clearly affect social life within the built environment, before analysing and understanding the relationship between the two. Core to this understanding is the analysis of architecture as spatial configuration of which Simmel has provided an initial step in his discussion and it is worth briefly returning to this (Simmel, 1909). Simmel's act of spatial separation clearly establishes a spatial enclosure or what one might call an architectural cell. Windows are used to connect to the outside space, while doors can be used to connect one cell to the outside or to another architectural cell. Multiple acts of separation and subsequent connection of spatial segments then lead to the establishment of a series of connected architectural cells or spatial configuration.

### **Architecture as spatial configuration**

Hillier defines configuration as the spatial condition that occurs when 'the relations between two spaces are changed according to how we relate one or other or

both to at least one other space' (Hillier, 1996). Clearly, at least three spaces are needed in this definition since the relationship between two linked or adjacent spaces cannot be fundamentally changed, as it is symmetrical. What is of interest here is the accumulation of architectural cells into larger configurations as seen in buildings and urban space. Although the possibilities in this process are numerous there are also clear limits and restrictions introduced by geometry and topology as Steadman points out (Steadman, 1983). Steadman's argument is not that these limits on their own would determine the actual design of a particular building program, but rather that they can make apparent the limiting factors that geometry places on the field of topological possibilities. To investigate these possibilities, the author introduces a dimensionless representation of architectural topology that disregards constructional elements like for example wall thicknesses. A series of different processes is elaborated on, manual and computer-supported, which are designed to enumerate all possible configurations that can be created with a set number of architectural cells, discounting isomorphs, configurations that are the result of rotational or reflective symmetries of the same shape.

This involves the introduction of a different representation of topological relationships: adjacency graphs (Steadman, 1983). Adjacency of spatial cells is clearly an important factor. When architectural cells are adjacent, they can be connected, while non-adjacency of specific architectural cells might be a requirement of a building program, for example for privacy or security reasons. In such graphs each architectural cell can be represented as a vertex and the adjacency of two cells as an edge. Two main types of adjacency graph can be identified: planar and non-planar graphs. Planar graphs are those that can be drawn without any of the edges crossing. They can be drawn in the plane and can be the basis of an actual building on the same floor level. Non-planar adjacency graphs cannot be drawn without edges that are crossing. These adjacencies are not realisable in an actual physical plan on the same floor level. Adjacency graphs can be used to investigate new architectural designs where an extensive set of possible plans might be automatically generated based on certain adjacency requirements, while at the same time the technique might be used for the description of existing buildings.

### 2.1.1 Architectural topologies and social life

Hillier & Hanson in turn focus on the relationship between architectural configurations and social life (Hillier and Hanson, 1984). Architecture structures physical space and this structure then has an influence on our movement patterns through that space, being partly responsible for determining who we encounter and who we avoid. At the same time architecture can also be described as a physical manifestation of the rules and norms of a particular society, partly readable from the outside. Two aspects are of concern here: the process of the assembly of architectural configurations and the influence these bring to bear on social life.

Beyond the geometrical rules introduced by Steadman, Hillier & Hanson suggest that the assembly of architectural cells can be described as being governed by local rules that together produce an overall recognisable structure. Through the application of such rules, continuous physical space is therefore transformed into discrete spatial units. For example, a rule might specify that each architectural cell is joined to another on one side and faces open public space on a second side. In an application of the above, it can then be shown that certain types of spatial order can be generated in simulation by applying such rules (Hillier and Hanson, 1984). The source of these rules is society itself; society acts as a restrictive influence on an otherwise random process. However, not all architectural configurations can be explained in this way as there are also global rules that are introduced by society with the aim of structuring space more actively and directly. Finally, the authors also argue that certain aspects of the applied rules are retrievable and through this the structure of a society can be recognised from its spatial configuration.

For a discussion of the influence these arrangements have on social life, it is necessary to return to the elementary architectural cell itself. Hillier & Hanson argue that one of its functions is to establish the two categories of inhabitants and strangers (Hillier and Hanson, 1984). Each architectural cell is owned by its inhabitant who controls its boundary or link to the outside public space. The inhabitant exerts control over the link to public space to maintain the discreteness of the category, to establish the identity of strangers and authorise the crossing of a link turning strangers into visitors. The public space outside individual cells

can be described as the interface of encounters between inhabitants and inhabitants and strangers.

A more concrete example of the relationships between spatial configurations and social life and the changes these relationships undergo over time is provided by Evans (Evans, 1978). For a specific historical period he set out to compare architectural plans and depictions of social life in the form of paintings. While architectural plans reflect human relationships, those are rarely depicted within them. Evans describes the reduction of plan permeability through the reduction of connections and the parallel introduction of corridors when comparing Italian renaissance building plans to those of 17<sup>th</sup> century England. Whereas proximity between people and their activities was valued in the former, the separation of activities was favoured in the latter. The function of the building plan was then to prevent the overlapping of certain activities and encounters especially between different social classes. Evans argues that over the last two centuries, the function of the modern architectural plan has become preventative, avoiding certain types of encounters, noise transmission, stemming vandalism etc. The above begins to show that above and beyond the interface to each architectural cell, it is architectural topologies, whether inside or outside of buildings that do have a direct effect on our movement patterns and who we encounter and avoid.

Hillier, in *Space is the Machine*, proceeds to systematically analyse the type of functional to spatial relationship that Evans observed. The keys to the analysis of this relationship are architectural configurations, not individual spaces themselves (Hillier, 1996). The analysis of spatial configurations in a large number of different contexts demonstrated a correlation between observed spatial regularities and observed movement patterns of aggregations of individuals through the said architectural configurations.

*"... the relation between form and function at all levels of the built environment, from the dwelling to the city, passes through the variable of spatial configurations. The effects of spatial configuration are not on individuals, but on collections of individuals and how they interrelate through space. All that is proposed, in effect, is that a pattern of space in a complex can affect the pattern of co-presence and co-awareness of collections of people who inhabit and visit that complex." p.379*

The key to understanding architectural configurations is their formal description in terms of their permeability. The adjacency graphs that were introduced above

can provide clear information about the spatial relationship of different architectural cells to each other. In addition to this, permeability graphs describe possible routes through a spatial configuration. To this end, spaces are represented as nodes and routes of access as vertices (Hillier, 1996). A graph is then justified from the perspective of a chosen starting point, the base of the graph. Often the exterior space is chosen, but this could be any space in the configuration.

This justified graph helps to express numerically the depth of a particular space in a particular configuration. Simply put, depth enumerates the number of vertices that need to be traversed to reach one space from another. The total depth for a space then enumerates how many vertices in the graph have to be traversed to reach each of the other spaces in the configuration separately, starting from the space in question. More details can be found in Hillier's overview of the various properties of justified graphs (Hillier, 1996). The value for the total depth of a space then indicates the relative integration of a space in the overall configuration. The lower its numerical value, the more integrated and integrating the space under scrutiny is, meaning that it is comparatively more central or pivotal to movement through the configuration. It can also be shown that an integrated space frequently has a very powerful visual field over the remainder of the configuration; i.e. the visibility of other spaces from such an integrated space is good in comparison to other spaces. Hillier adds that the analysis of samples of architectural plans can show that the way that certain types of functions are assigned to spaces frequently depends on their integration in a configuration (Hillier, 1996). This allows the analysis of cultural aspects of the architectural plan in an abstracted way, by comparing permeability and visibility within an architectural configuration to its functional properties.

More importantly in the context of this thesis, the overall distribution of integrated and less integrated spaces can be shown to correlate well with observed movement patterns of aggregations of individuals. More integrated parts of a spatial configuration attract higher rates of pedestrian and vehicular flow and this effect can be predicted without invoking individuals' motivations or functional properties of the environment (Penn, 2003). Beyond these lower level effects of movement probabilities, Hillier argues that spatial configuration also affects the smaller scale spatial milieu that people occupy.

*"Through its effects on movement, spatial configuration tends naturally to define certain patterns of co-presence and therefore co-awareness amongst the individuals living in and passing through an area. Co-present individuals may not know each other, or even acknowledge each other, but ... this does not mean ... that co-presence is not a social fact and a social resource."* (Hillier, 1996)

This 'virtual community' of co-present and co-aware people is on a fundamental level the result of the spatial configuration it occurs in, which influences the flow of people, the density of people and the interface between different groups of people such as inhabitants and strangers or adults and children, for example (Hillier, 1996). Hillier argues that this in turn can affect behaviour patterns in terms of what is deemed appropriate in which type of space.

Penn et al then reflect on the effects of spatial configurations on social interaction within buildings with the aim of providing predictive models that could help architects in future (Penn, et al, 1999). In their review of two research-led building projects for organisations that rely on innovation for their success the authors show how the frequency of contact between office-based workers is directly affected by space use and movement patterns in turn resulting from spatial configurations. The background to this work is the rapid change that modern organisations experience, and the fact that buildings are used to accommodate some of that change often without a clear understanding of how it might affect the workings of an organisation. In addition, Penn et al cite previous research by Allen, which has shown that teams of innovators need creative input from outside the immediate team to sustain themselves (Allen, 1977), to argue that buildings should facilitate or least not be in the way of such contacts (Penn, et al, 1999). In turn, their own research has demonstrated that who is found 'useful' in an organisation correlates well with where they are located. People located in an integrated space were those that were seen most often and rated as most useful, even after discounting their roles or level of seniority (Hillier and Penn, 1991).

The following briefly summarises the main findings from the two case studies that Penn et al present (Penn, et al, 1999). The first was a new building for a utility company, the post-occupancy study of which had shown that the new design was indeed more generative in terms of social interaction than the previous building. This was achieved by avoiding too many segregated spaces in this open plan office and 'distributing' integration evenly from the central corridor to the



peripheral spaces. Interestingly though, spatial integration went only so far, as local group identities were then reinforced by team leaders who had control over local space partitioning and design. The second case-study was of an advertising adjacency located on two different floors. In an application of the Space Syntax technique (Hillier, 1996, Hillier and Hanson, 1984) (for a succinct overview of the technique see (Bafna, 2003)), movement rates were shown to correlate with the level of spatial integration on the upper floor. Here global to local movement was connected with the most integrated space, which in turn had the highest rates of movement. Also, differently integrated spaces were shown to map to different activities with movement occurring in the shallow spaces, sitting in the deeper spaces and standing occurring somewhere in-between. Movement rates dropped with greater depth of a particular space (Penn, et al, 1999). In contrast, on the lower floor, global to local movement and internal movement were separated, there was a segregated additional corridor that took a substantial amount of movement and core attractors on this floor were removed from the main circulation areas. This resulted in opportunistic interaction between passers-by and people located in this space being strictly controlled as they were fundamentally separated from each other and in a reinforcement of internal communications on this floor over communication across the whole organisation, an exchange that has been identified as vital for innovation (Penn, et al, 1999).

Penn et al point out that this shows in turn how spatial structure can be designed to integrate people (e.g. an open plan office) or to segregate them (e.g. cellular offices), by changing the level of integration of the actual spaces themselves. In fact this is a common feature of modern organisations, where people who are higher up in the company's hierarchy occupy the most segregated or deep spaces. It is argued that this has a clear effect on social structure. Segregating people in space controls their availability to others with the tendency to conserve existing social structures, while measures of integration can produce a generative environment in which new social contacts are frequently made. However, Penn et al point out that designing for spatial integration on its own with the aim to provide a more generative spatial environment in terms of social structure is not sufficient to provide for a flexible working environment and spatial segregation might be needed to enable different activities (Penn, et al, 1999).

Backhouse et al in turn argue that for a full understanding of social interaction within the work place, research needs to look beyond the influence of spatial configuration alone (Backhouse and Drew, 1992). Using an ethnographic methodology, focussed on the collection of video data but also using other sources, the authors aim to gain an in-depth understanding of the setting concerned, a large open office space connecting a number of smaller offices. In their analysis they set out to identify emerging patterns of behaviour and described those in detail. Backhouse et al describe the organisation of work as a complex negotiation of interactions around two separate 'task spheres', the immediate task at hand and the task of recruitment (Backhouse and Drew, 1992). When concentrating on work at their work station, workers are generally seen as unavailable for interaction. When they get up and move to other areas, they become available for 'recruitment' for social interaction by others but also initiate social interaction themselves. Both parties, those remaining at their desk and those walking around can be seen to scan the corridors and the work area respectively, with the aim of establishing social interaction.

Over and above the influence that spatial configuration has on co-presence and awareness, who is approached is the result of professional relationships that have grown over time and is not necessarily determined by the spatial configuration that was imposed on people by management. What the above demonstrates is that spatial configuration can facilitate encounters, in the sense that it does so, if it does not inhibit those (Penn, et al, 1999). However, more fine grained analysis and observations are necessary to understand the significance and purpose of those encounters and what turns them in to social interactions (Backhouse and Drew, 1992).

### **2.1.2 Dynamics**

One defining characteristic of the spatial configurations described above is that they are comparatively stable. Change tends to be slow simply as a result of the physicality and size of buildings. Of course, Hillier points out that while the architectural configuration itself may be fixed, it will appear very different from different perspectives within it, which the author demonstrates with a series of examples of justified graphs for a selection of spatial configurations (Hillier, 1996).

*"... a pattern of space not only looks different but actually is different when justified from the point of view of its different constituent elements." (Hillier, 1996)*

The critical point here is that the relative depths of parts of the configuration change with the observer's movement through it, making those parts more or less accessible in the process from an individual's point of view.

Clearly though, this does not change the fact that architectural configurations remain static as long as their constituent parts do not move physically. While on the one hand this medium to long-term topological stability does provide for a stable basis for societies to develop within, it does on the other hand appear to clash with our fast-moving world and societies that frequently overcome physical spatial limitations with technological means, as will be discussed in sections 2.2 and 2.3.

However there are various ways in which architecture can adapt to changing needs, although in a relatively measured and slow way. Steadman considers different forms of adaptability from a configurational perspective (Steadman, 1983). He argues that in most cases organisations are fitted around existing buildings, as the least costly option. This can apply to changes in the same organisation but also to new organisations moving into an existing building. Alternatively, there can be internal adaptations or external extensions to a building's structure. Adjacency requirement graphs can then be employed to list the different ways that a particular organisation might fit into an existing building. Extending this approach, Hillier considers the effects of such changes on the integration of the overall configuration (Hillier, 1996). Adding a single architectural cell or changing the location of an existing one, can influence the configurational properties of many others and may be all others in the configuration under investigation. At the same the properties of the entire configuration may also change as it becomes more or less integrated overall as a result of the change of just one of its cells.

Of course building adaptations are a very common way of dealing with social change and Heath outlines what might be the most widespread form in the UK currently, the re-use of industrial and commercial buildings that have become obsolete as result of the ongoing shift from manufacturing to services (Heath, 2000). These buildings often located close to the city centre are frequently converted for residential uses. This not only provides a short term solution for

housing shortages but can also be seen as part of a wider strategy for more sustainable building development.

In a much more detailed fashion, Brand reflects on the different aspects of change that occur within buildings (Brand, 1994). Although they are built for permanence he argues for buildings to be managed not just in space but also in time as a reflection of the fact that buildings will be changed by their owners as well as occupiers regardless of the architect's original intentions. A number of factors such as the advent of new technologies, the financial situation of owners but also fashion are driving this change. The rate of change varies widely between commercial buildings, where it is rapid, to domestic, where it is steady and ongoing and institutional, which can be said to be built to prevent change internally and signify stability to the outside. Furthermore, Brand, with the help of a series of fascinating before and after photographs and plans, argues that the rate of change varies inside the same building. Elements like the site and the building structure often change very little over time. Adaptations to the building skin and its services are much more frequent. Finally the partitioning inside a building can change quite frequently, at least in a commercial context while what Brand calls 'stuff' (furniture objects, etc.) might change on a monthly or even daily basis. As a response he calls on architects to design for space and time with the hope that buildings will result that occupants can adapt themselves in a bottom-up rather than top-down approach, without the designer precluding too much of the building's possible future uses.

A more radical approach is proposed by architect Cedric Price (Price, 2003). In his Generator Project of 1978 buildings consist of separate physical cells that are assembled and adapted according to the needs of their inhabitants, with the building learning over time what might be required. Certain aspects of this have been taken forward to the construction of the Interaction Centre, a small cultural centre that was designed to be adaptable. When it comes to the building stock in Western societies however, it is clear that the vast majority of buildings are fixed in place. Exceptions to this rule can be related to a different life style (e.g. modern nomads making use of mobile homes), particular technical constraints (e.g. the raising of whole buildings to allow for a new sewerage system (Roberts, 1999)) and the perceived historical value of a building (e.g. the relocation of the Belle tout lighthouse (BBC, 1999)).

An entirely different perspective on architectural change is taken by Novak when he considers architecture designed for and constructed in a different spatial medium: virtual space (Novak, 1995). Novak's response to digital media already allowing us to overcome space to establish co-presence is to argue for an architecture that can be transmitted across networks, virtual architecture designed in space and time. Moving architectural design into virtual space allows the speeding up of change from the slow pace discussed in the sections above. In a very different way from Brand, time can be an active design element in architecture. The change of variables of algorithms that create architectural form could be part of a pre-coded scheme but might also react to inhabitants, creating architecture that Novak calls animate or at least animated, in a sense reflecting in a more radical way what Price had suggested for physical space.

Similar techniques have then been employed to further the design process of conventional physical buildings. Examples include Greg Lynn's port authority project, where the architect used the simulation of various traffic flows to directly inspire the design (Zellner, 1999) and the freshH2O eXPO project by NOX, a pavilion exhibiting fluid shapes that uses sensors to react to the presence of people by displaying different graphical projections and audio content in the interior (Zellner, 1999). However, both the above designs remained spatially static once they were built. They remained in place and did not change internally in terms of their spatial properties. In contrast, Oosterhuis Associates in collaboration with Marcos Novak proposed a project that would react spatially, the transPORTs2001 project (Zellner, 1999). The physical building would be able to expand and contract with the help of pneumatics and a stretchable building fabric, as a reaction to people interacting via the web. Although it was never built, it presents an intriguing combination of Price's earlier concepts of dynamic buildings with the interactivity provided by the Internet.

## ***2.2 Architecture and communication technologies***

As has been pointed out, architecture is not the only phenomenon that influences social interaction. Communication technologies enable us to interact across distance, asynchronously and synchronously. On the one hand they can be said to establish their own structure and topology but on the other hand the two are

clearly always related. This is because communication technologies have a physical form since they need to be installed into the existing urban fabric.

Steadman reflects on the influence of long established telecommunication technologies on the structure of cities in interaction with transport technologies (Steadman, 1999), with the aim of better understanding the possible effects of the Internet, a much younger technology whose effects on urban form are not clearly visible yet. The middle of the 19<sup>th</sup> century saw the wider deployment of the electric telegraph in the USA and Europe, often along existing transport routes, like railway lines. Development was rapid. In 1851 the first telegraph line between France and England was installed, while in 1866 the first transatlantic line was established (Steadman, 1999). Initially, relatively long distance communication was faster than that within a city, which still relied on sending physical messages. This led to the emergence of the central business district where access to the telegraph technology was provided and whose activities such as financial transactions for example, benefited most from face-to-face contact and interaction. As a result and due to the fact that the telegraph did also become available within cities at a later stage, many firms separated their headquarters from sites of production, which were pushed out to the periphery, where land values were lower and more land was available. Communication with the headquarters was then achieved via the telegraph.

The introduction of the telephone network in the late 19<sup>th</sup> century and its massive growth during the middle of the 20<sup>th</sup> century brought similar changes. In contrast to the point-to-point electric telegraph the much more flexible telephone was based on a network structure with exchanges, it was interactive and allowed synchronous social interaction. Because of technical difficulties with long distance telephony, telephone networks were initially deployed within buildings and within the boundaries of cities. This effectively reversed the pattern of connectivity compared to the telegraph, where long distance connections were initially favoured over local connections. However, Steadman observes that the effects on urban structure were similar (Steadman, 1999). The introduction of the telephone had the effect of dispersing certain functions but concentrating others, where face-to-face contact was particularly valuable. Smaller firms, warehouses and sites of production could all move to the periphery but stay in contact with the

centre, whose dominant position as the site for companies' headquarters was reinforced.

*"Here are the beginnings of a process of dispersal of those commercial and industrial functions for which space, cheap land, easy access to out-of-town transport routes or direct access to new suburban markets were important; this was balanced by the reverse process of concentration of those functions for which spatial proximity and face-to-face contact remained important, even at the cost of higher rents and traffic congestion. The two processes went on throughout the twentieth century."* (Steadman, 1999)

These factors played a major part in transforming cities in the developed world from centres of manufacture to service centres, concentrating financial, legal and administrative functions. Telecommunication and information technologies then saw huge growth in the second half of the 20<sup>th</sup> century. Interestingly, the new global communication network followed existing traditional trade routes and Steadman suggests that there was a clear positive feedback effect between the two (Steadman, 1999). So instead of decreasing the amount of travel required, which has often been predicted to be the result of the increased availability of telecommunication technologies, these developments have most likely led to an increase in travel, albeit possibly of a different kind. Related to this was the observation that rather than initiating new contacts with people further away, the telephone was used much more to reinforce already existing local contacts.

More importantly in the context of this research is the spread of the Internet that grew from a small research network in the 1960's to span the entire globe and encompass millions of nodes today. Its growth was so rapid because it occurred on the back of existing hardware put in place for other purposes (Steadman, 1999) and because it coincided with the rapid increase in power of microprocessors constituting the nodes and switches that make up this new network. Castells argues that this revolution in information technology was more than just another step in technological development (Castells, 2004). It led to a paradigmatic shift from industrialism to informationalism. While industrialism, associated with the industrial revolution, is concerned with the organisation of technologies driven by the production and distribution of energy derived from natural resources, informationalism 'is a technological paradigm based on the augmentation of the human capacity of information processing and communication made possible by the revolutions in microelectronics, software, and genetic engineering' (Castells,

2004). The author stresses that industrialism was not simply replaced by informationalism. After all, the provision of energy and the technologies associated with industrialism are still vital to informationalism. He also outlines how the revolution in information technology quite accidentally coincided with two other major developments: the restructuring of industrialism during the 1980's, and the cultural movements of the 1960's and 1970's, and how these three factors affected the structure of western society (Castells, 2004). Taken together, the revolution in information technology, the restructuring of industrialism and the changes in the value system of western societies lead to what Castells calls the network society (Castells, 2004).

*"A network society is a society whose social structure is made of networks powered by microelectronics-based information and communication technologies. By social structure, I understand the organizational arrangements of humans in relations of production, consumption, reproduction, experience, and power expressed in meaningful communication coded by culture."* (Castells, 2004)

Castells provides a detailed overview of the characteristics of the network society (Castells, 2004). In the context of this thesis, aspects that concern its topological structure are most relevant and a brief overview will be given here. By definition, as the underlying network is global, the network society itself is also a global phenomenon. While it affects everyone, not everyone is included as the global network selectively connects certain sites, groups or individuals, leaving out others at the same time. This selectiveness in terms of connection is a fundamental feature of the network technology (Castells, 2004). In turn, this can have a segmenting effect on existing societies, as certain parts are left behind unconnected. In that sense, connection is a prerequisite to participation in the network society. However, it cannot guarantee it as there are other mechanisms in place that differ from network to network (Castells, 2004). It must also be clear that the network society is based on many different networks with their own topologies. These networks emerged on the basis of existing values, interests and projects, and for an understanding of the network society, global and local aspects need to be considered.

Mitchell in turn identifies a general shift of a whole set of human activities away from physical space towards and into digital environments and outlines some clear differences between the physical and digital domains (Mitchell, 1995). In



physical reality activities tend to be separated in time and space. Districts in a city or zones in a building can make these visible to the outside. Crossing from one zone to the other is also visible to others, often resulting in the location of an individual becoming a clear indicator for their activity and also status (Mitchell, 1995). This 'civic legibility', as Mitchell calls it, is a defining and crucial aspect of our physical environment. More and more activities that used to be housed in and framed by identifiable buildings (e.g. libraries, banks, shopping malls etc.) can now be conducted digitally (e.g. the digital library, telephone and online banking, catalogue and online shopping).

*"... the worldwide computer network - the electronic agora - subverts, displaces, and radically redefines our notions of gathering place, community, and urban life." (Mitchell, 1995)*

At the same time, with digital technology it becomes easier to design buildings in a way that allows them to accommodate different functions; they become programmable (Mitchell, 1995). Cities will not disappear in the process, but Mitchell predicts that their use will change and that the distribution of functions will be more homogenous since access to services becomes independent of location.

Electronic environments in turn have changed this even more extremely. In context of these, place often has no meaning anymore, although there are of course various attempts to introduce its concept (Mitchell, 1995). Awareness of others and social interaction have effectively been de-spatialised. Mostly, boundaries still exist but access and exclusion are not structured in traditional architectural terms and crossing boundaries is replaced by following logical linkages. Within such environments it is not easy to read anymore who is doing what where. 'Civic legibility', in the sense it is provide in purely physical environments has been lost. This is exacerbated by the fact that anyone can take on different identities (Mitchell, 1995). This could take the form of different aliases representing an individual in different contexts or it might be that person chooses to be represented by an agent in certain circumstances. This has clear effects on the establishment of trust, as in many circumstances it cannot be clear anymore, where a message is originating from.

Benedikt, taking this a step further, considers the fundamental properties that entirely virtual environments might and should have in *Cyberspace: Some Proposals* (Benedikt, 1991). The author introduces the concept of Cyberspace as a 'globally

networked, computer-sustained, computer accessed, and computer generated, multidimensional, artificial, or virtual reality' (Benedikt, 1991). This space is created from data either as a representation of physical space or independent of it and he argues for it to have 'a geography, a physics, a nature, and a rule of human law' (Benedikt, 1991), which takes it beyond what is currently available in terms of the World Wide Web, although online communities like ActiveWorlds™ (Activeworlds, 2004) might come closer to this concept.

Benedikt argues for Cyberspace to be created to allow people creative expression, productivity and control over their lives but also as a contrast to and platform from which to reassess the value of physical reality itself. In his definition of space, the author adopts a phenomenological standpoint, arguing that space, from the point of view of everyday experience, can be described in terms of what it feels like to us and what it affords. Space allows us to move. We are in space and are spatial ourselves. Space cannot be by-passed when relocating; there is always an element of travel. These principles can and should be taken forward to the design of virtual spaces. Benedikt points out that while virtual spaces do not have to adhere to the laws of physics necessarily they do need to be internally consistent, pragmatic, adjusted to human needs and accessible to ordinary people without special training, in what he calls good computer science tradition.

*'Even as we strive for higher dimensionalities or supernormal capabilities for the denizens of cyberspace, ordinary space and time must form the basis, the norm, any departures from which we must justify.'* (Benedikt, 1991)

So although the rules that govern physical reality can in principle be violated there will be a trade-off when it comes to the comprehensibility and credibility of a virtual space. Finally, Benedikt also argues for Cyberspace to be understood as a place, not a technology or mere simulation of reality. It is independent from physical space in its existence and should also exist independently from any particular interface technology to access it; in fact it should be accessible with a variety of such technologies. The author then sets out to discuss a number of design guidelines for the future establishment of virtual space, which are concerned with providing people with a useable and comprehensible environment. He describes virtual spaces as information fields and discusses their dimensionality, continuity, limits and density, the discussion of which goes beyond the scope of this thesis (Benedikt, 1991).

While Benedikt proposes design guidelines for virtual environments that are based on the notion that their properties should not diverge too much from that of physical reality, clear structural similarities between the two categories of environment can already be found in existing environments. Mitchell points out that the overall structure of virtual environments often resembles that of physical ones (Mitchell, 1995). In those cases a city metaphor is employed by the designers to structure activities of inhabitants. This includes public and private areas and the social norms and customs that go along with these. Schroeder identifies similar effects in ActiveWorlds™, an online virtual environment available over the Internet, in which inhabitants have the ability to construct virtual buildings from a library of objects and therefore shape their geographical and social environments (Schroeder, et al, 2001). While the owner of a particular world within ActiveWorlds™ might provide some initial structure, like a public building in the centre for example, building is otherwise pretty much unrestricted. Nevertheless, Schroeder points out that a variety of features of the geographies and forms of social interaction have been incorporated from physical reality, which are also balanced with utopian and science fiction influences (Schroeder, et al, 2001).

Another direct influence that physical reality has on virtual environments is through the reliance of the latter on the underlying network infrastructure, which itself is of course physical. The power of the networks to selectively connect but also exclude sites, groups and individuals has already been discussed (Castells, 2004). Steadman adds that communications between already existing centres of activities are being further improved with the installation of network technologies, a trend that can also be identified with the earlier technologies such as the telegraph and the telephone. Their installation followed existing trade routes and later connected the same places as the international airlines did (Steadman, 1999). Mitchell argues that the effect is now even reinforced due to the fact that the new networks, unlike the telephone network, are not subsidised anymore to provide equal democratic access. Instead, teleports emerged in key physical locations that provide high bandwidth access to the network to people who are physically located there. Consequently, no connection or low bandwidth at a physical site can result in its marginalisation, virtual and physical (Mitchell, 1995).

Finally, early commentators might have underestimated the degree to which people are actively using digital and physical environments simultaneously.

Technologies like the Global Positioning System (GPS), which has recently become more widespread, already bind them together in a very direct way (Mitchell, 1995). GPS provides digital information on the basis of its user's physical position, a technology which has for example been explored for portable tourist guides (Cheverst, et al, 2000). Arguably, the ubiquitous availability of mobile phones reinforces that connection, as comparatively simple location aware services also become widely available, like for example the Trip-test system that allows commuters on Nottingham's Tram system access to up to date time table information based on their current location (Nottingham Express Transit, 2004).

With the above considerations about the already existing relationship between the two types of environment in mind, Mitchell calls for architects to develop physical and digital places in parallel; to design for both so to speak.

*"(Architects) ... will be forced to explore the proper respective roles of physically constructed hardware and symbolically encoded software, and of actual space and virtual places. And eventually they will find new ways to accommodate human needs by recombining transformed fragments of traditional building types in a matrix of digital telecommunication systems and reorganized circulation and transportation patterns."*  
(Mitchell, 1995)

The author reiterates his ideas in *E-topia*, where he provides more details of how the digital and physical environment will interrelate from the architectural to the urban scale (Mitchell, 1999). This clearly goes beyond simply adding technology to buildings but is much more fundamental. Both sides of the interface between physical and virtual places need to be considered. How this can be done in an architectural way is the fundamental subject of the research presented in this thesis. As a next step however it is worth investigating a number of specific telecommunication technologies for a better understanding of their general properties and how they support social interaction at a distance.

### ***2.3 Technologies for remote communication***

The aim of all telecommunication technologies is to enable people to communicate with each other at a distance as a substitution for physical co-presence. As has been discussed above, this can take place in an asynchronous way as with ordinary mail, email and electronic bulletin boards, for example. However, the

term telecommunication typically refers to synchronous communication between dispersed individuals or groups of people, available in form of a variety of technologies such as the telephone, videoconferencing and others.

In the context of this thesis, it is now crucial to look at some relevant communication technologies in more detail with the aim of understanding their technical characteristics but even more importantly their impact on social interaction at a distance and their influence on architecture. There have been a number of approaches to telecommunication that specifically attempt to address the lack of spatiality of other technologies and what follows is a review of developments in the three relevant research areas of Media Spaces, Collaborative Virtual Environments and Mixed Reality.

### ***2.3.1.a Media Spaces***

Telecommunication over video and audio has its roots in video telephony, which was made publicly available in the 1970's in the USA and remains fundamentally unchanged up to the present day (Fish, et al, 1993). Video telephony, typically providing one to one communication, has not proved a commercial success although versions of the same idea have been implemented across the Internet and more recently on mobile phone networks. An extension is video conferencing that includes more than one party in a single call. Fish et al argue that most of the development originally focussed on comparatively formal occasions (Fish, et al, 1990). Video conferencing in office settings for example, was typically set up in dedicated rooms. Meetings were scheduled with certain participants and focussed on an agreed agenda, which made interaction relatively inflexible. Reynard adds that video conferencing was designed to support short term, focussed activities with little support for general awareness beyond that of the people directly involved (Reynard, 1998).

This type of interaction of course only covers a small portion of how people interact when they physically meet. Meetings are certainly arranged but a lot of interaction tends to be much more informal (Fish, et al, 1990). This interaction takes place in an ad hoc way with randomly encountered participants and an evolving agenda that is interactively negotiated between at least two but often more participants.

Media spaces are a group of technologies that were derived from video conferencing to include more informal, less organised conduct in telecommunication technologies. In fact they were often seen as effectively simulating interaction in physical space. Gaver however is critical of this view in his analysis of the affordances of media spaces (Gaver, 1992). Reynard adds that media spaces in contrast to video conferencing technologies aim to provide a medium for background awareness as well as focussed interaction, tend to be set up for longer periods of time and might offer different types of video service (Reynard, 1998). Reynard also argues that the boundary between video conferencing and media spaces has been blurred over time and Fish et al call for systems designed for informal communication to be adaptable to more formal and task-focussed forms of interaction (Fish, et al, 1993). What follows is an overview of some implementations in four application areas that are directly relevant to the implementation of MRA as described in later sections of this thesis. These are the support for distributed presentations, the support for distributed groups, remote office shares and finally the connection of remote public spaces.

### **Distributed Presentations**

Media spaces have been implemented in support of distributed presentations, where a speaker and all or parts of their audience are not co-located. Isaacs et al describe Forum, a system that broadcasts presentations by a local speaker to remote audiences using video and audio (Isaacs, et al, 1995). Speakers and audiences communicate via audio or text, and audience members communicate with each other using a text chat facility. The Telep system (Jancke, et al, 2000) allows local as well as remote audiences to attend a presentation. The speaker gives a talk in front of a local audience, but is also presented with a video representation of the remote audience. Remote audience members see a live video window on their desktops, but communication takes place via text. Mark et al have studied the use of MSNetmeeting to support distributed groups at a large corporation (Mark, et al, 1999). This system features application sharing and a shared whiteboard, supported by telephone conferencing without the transmission of video.

### **Distributed groups**

Additionally a number of tools have explored the connection of distributed workgroups to establish a sense of awareness but also for communication purposes. Dourish et al describe Portholes, a tool that provides awareness

information to a group of work colleagues distributed across two sites. The interface presented users with regularly but infrequently updated glances into connected offices and public spaces. Audio messages could be left for others, images could be manually updated and email could be initiated by clicking on one of the images. A trial over more than 8 months suggested that more awareness between the remote sites had been established and informal communication across other channels had increased. Mantei et al introduce Cavecat, a media space for a group of four people (Mantei, et al, 1991). The views of all four can be tiled on a small screen with the help of a separate computer interface based on a spatial metaphor. Users can initiate meetings by moving representations of others into the configuration they want.

### **Remote Office Shares**

In a more private context media spaces have been set up as office shares, characterised by the linking of just two offices into one entity. Adler et al reflect on a persistent unswitched video and audio link between their offices (Adler and Henderson, 1994). In a related paper, Dourish et al summarise the findings of a similar link that was in operation for around three years (Dourish, et al, 1996). In both cases small analogue screens with attached cameras and omni-directional microphones were placed on participants' desks with an always-on connection between them. The authors emphasised the benefit of extending communication across physical space despite the fact that the technology operates very differently from interacting in physical space.

### **Connecting Public Places**

Probably the first time video conferencing technology was used specifically for informal interaction was for 'Hole-In-Space', a piece of multimedia art by Galloway & Rabinowitz (Galloway and Rabinowitz, 1980). Two outdoor public spaces, one in New York and one in Los Angeles were connected for three days with a synchronous video and audio link to an enthusiastic public reception. VideoWindow was a much more focussed three month trial of a persistent media space in an office setting (Fish, et al, 1990). Two common rooms on different floors of the authors' organisation were connected with an always-on media space implemented as large, wide screen display, which allowed the projection of life-size images in the respective remote space. Being near the interface on either of the two sides was all that was needed to establish communication. Jancke et al de-

scribe a media space linking three coffee kitchens in an office setting (Jancke, et al, 2001). In each space a large projection presented one's own view, the view of the other two spaces and a panel displaying a news channel, added as a conversation starter. This was combined with an open audio connection.

### **Common issues in Media Space research**

Although the above examples cover a wide range of application domains and implementations, there are a number of re-occurring issues that are being addressed. Some key findings that are worth briefly summarising here concern issues of awareness, communication, privacy, community, the installation site and comparisons with interaction in real space.

Media spaces were shown to be supportive of awareness between the key members of a connected group. However, they had difficulties in supporting participants to become aware of events in the periphery at the remote sites (Adler and Henderson, 1994). These included for example events in the background of the camera view, the general situation at the remote site and objects as well as participants just outside camera shot. However, the level of awareness that was provided did help to generate a sense of community (Dourish and Bly, 1992). Formal and informal communication were both supported, in addition to awareness (see above) and focussed discussions. For this purpose, audio and video were regarded as necessary (Fish, et al, 1990), while the quality of these channels could well be lower when supporting awareness only (Dourish, et al, 1996). In terms of privacy, a number of further issues were identified. The nature of certain conversations could lead to conflicts as the interface can be private but also very public, depending on who was present (Fish, et al, 1990). This was less of a problem for smaller groups of people well known to each other, who also had control over their local space (Adler and Henderson, 1994). Mantei argues that this control should be extended to controlling the connections within the media space (Mantei, et al, 1991). However, even then, it appeared that privacy remained a concern for a minority of people, especially when interfaces were installed in public spaces (Jancke, et al, 2001).

The community effects are also worth reflecting on. Even connections between just a pair of people were shown to have an effect on the community as it was used by others close by (Dourish, et al, 1996). However, it was also argued that if the prime aim was to establish a community, it was best to connect an existing



group (Dourish and Bly, 1992) or concentrate suitable partners (Fish, et al, 1990). Connecting strangers, especially over public interfaces, did not in itself lead to more contacts or an increase in the social network (Fish, et al, 1990) (Jancke, et al, 2001). How people interact within that community evolves over time, building up an etiquette of what is acceptable and what is not (Dourish, et al, 1996).

Additionally, the sites for the installations of media space nodes were identified as important. Here it was clear that different types of interaction could be expected, depending on where the interface was located. In particular, public spaces could be shown to generate limited conversational and sustained use (Jancke, et al, 2001). When installing the technology, its orientation in relation to other technologies and its orientation for other connected sites needed to be considered (Dourish, et al, 1996), while no control over the participant's set-up should be expected (Mantei, et al, 1991) and rearrangements at a later stage were likely (Dourish, et al, 1996). Finally, when compared to interaction in real space, interaction in media spaces was clearly different (Mantei, et al, 1991), but it provides enough benefits to make media spaces worth while supporting, especially when considering that people remote from each other were connected. In fact, Dourish et al argue that interaction in physical space is the wrong base line for the evaluation of media spaces in the first place (Dourish, et al, 1996).

Some of the problems introduced above might be said to result from the very particular nature of media spaces themselves and this is worth investigating in more detail as it has influenced research in other areas. Media spaces, although the name might suggest otherwise, do not embed the users of this technology in their own spatial framework; they do not provide a space for communication to take place 'within'. The spatial framework created by Media spaces is physical, linked by technology, not fundamentally different from the phone network. Therefore, as Virilio suggested (Virilio, 1997), they de-spatialise communication and cannot provide civic legibility, suggested by Mitchell to be so critical for interaction in physical space (Mitchell, 1995). Additionally, the fact that media spaces do not provide an internal spatial framework also leads to interactional problems. Researchers have reported that participants in media space sessions find it difficult to understand what others experience. Without an internal spatial framework, it is difficult to see what and who others are attending to, what they are pointing at or who they might be facing, as people's conduct is separated

from the space it is produced in and from the space where it is received (Luff, et al, 2003). There have been two major sets of technologies that particularly addressed these issues, by introducing spatial aspects into remote communication: spatial video conferencing and collaborative virtual environments.

Spatial video conferencing attempted to address the smaller scale interactional problems by arranging multiple video views into a spatially consistent framework, for example, overlaying them on a semi-transparent drawing surface (Ishii, et al, 1992); through an arrangement of small displays and cameras in a semi-circle in the HYDRA system (Sellen, et al, 1992); or larger projected semi-transparent displays and cameras as with the MAJIC system (Ichikawa, et al, 1995). These systems are characterised by making use of physical space as the spatial framework that communication is embedded in. However the focus here is on a technology for remote communication that does introduce its own internal spatial framework. This will be discussed in the following section.

### ***2.3.1.b Collaborative Virtual Environments***

In response to some of the issues presented above, researchers in Computer Science started to explore Collaborative Virtual Environments (CVE), a specific form of media space, placing people in the same spatial framework and aiming to simulate the affordances that physical space can provide. CVEs have their roots in the development of Virtual Reality, the interactive computer simulation of real or imagined environments in three dimensions, which can be explored with the use of a variety of interfaces, ranging from desktop computers to fully immersive projection facilities.

While virtual reality was originally designed for single users, research quickly turned to creating virtual reality for group collaboration, which is distributed over a computer network to allow interaction across different physical sites (Greenhalgh, 1999). According to Greenhalgh, CVEs are characterised by providing a spatial frame for interaction that allows their users to move independently, while being represented to themselves and others with a visible embodiment or avatar. He argues that this allows for communication being supported by spatial cues, like gaze or gestures for example, which are modelled on physical reality; and that it provides a sense of awareness of others' activities in the shared virtual space. In fact, awareness management is a key factor in CVE design that is used

as a tool to limit communication requirements between users in an effort to make systems more scaleable. Typically environments are partitioned to that end and this can happen along three different lines: space, content and semantics. These can also be combined. Most relevant in the context of the research presented here are spatial approaches. The virtual environment itself can be partitioned into smaller regions or locales (Barrus, et al, 1996). It can then be specified how much a particular user needs to be aware of locales they are not located in. A different approach, on which Greenhalgh bases his work, is the spatial model of awareness (Benford and Fahlén, 1993). Here communication between objects is controlled on the basis of the distance and orientation established between them. For example, this allows the automatic establishment of a communication session between two users of the same CVE, as soon as they are virtually close to each other.

CVEs have been studied extensively in a variety of contexts, and what follows is an overview of some key developments. CVEs have been developed for teleconferencing applications. Ståhl introduces DiME, enabling small groups of participants to meet remotely for project work (Ståhl, 1999). Frécon et al describe a persistent CVE modelled on the concept of team rooms, environments providing tools and facilities to support collaborative work (Frécon and Nöu, 1998). More specifically, CVEs have also been used to support collaborative design activities. Takemura et al propose a CVE, using a graspable interface, to support design tasks by allowing dispersed users the direct manipulation of virtual objects (Takemura and Kishino, 1992). A system for distributed design reviews is outlined by Daily et al, which allows visualisations to be displayed on diverse interfaces to distributed teams (Daily, et al, 2000). Another notable application area is that of online performance. Benford et al proposed and implemented Inhabited TV, combining a CVE with broadcast television, with the aim of allowing online users to participate in a TV show produced from within such a CVE (Benford, et al, 1999); while Craven et al suggest various interfaces to make sense of the resulting non-linear narrative (Craven, et al, 2001). Finally, CVEs have also become available to the general public in a variety of guises. Schroeder et al focus on the different factors affecting trust in virtual environments in a study of long-term users of ActiveWorlds™, an online virtual environment available over the Internet (Schroeder and Ann-Sofie, 2000), and on how inhabitants are able to shape

their geographical and social environment by building virtually inside the environment (Schroeder, et al, 2001).

While certainly not exhaustive, the above overview covers a wide range of application domains. Although it is clear that the spatial nature of CVEs provides advantages in terms of the awareness that participants can gain of others there are also problems that remain. The two most relevant in the context here are the limited interactional feedback provided by avatars and the limited physical context provided through CVEs. Regarding the first issue, researchers realised that although even the simplest of embodiments can convey a certain degree of interactional feedback, they are restricted when it comes to more fine-grained interaction (Bowers, et al, 1996). Relative positions to others and orientation can be conveyed, while facial expressions or gestures cannot easily be shown, unless an expensive heavy technical investment is made (e.g. full body and facial tracking). Bowers et al also argue that the typical implementation of CVEs as desktop environments precludes giving remote participants a sense of the local environment (Bowers, et al, 1996). Activities in real and virtual space influence each other and it must be possible for these activities to be displayed on both sides of the link between physical and virtual space, an argument not unlike Mitchell's call for a design of physical and virtual architectures in parallel, mentioned previously (Mitchell, 1995). The field of Mixed Reality, introduced in the following section, was partly driven by the above considerations.

### ***2.3.1.c Mixed Reality***

Mixed Reality aims to merge physical and virtual spaces into a coherent framework so that objects and people from both domains can interact with each other. In their taxonomy of Mixed Reality visual displays, Milgram et al describe the relationship between real and virtual spaces as a continuum, with different 'mixes' of the two domains available in different technologies (Milgram and Kishino, 1994). With physical space and virtual space at the extremes this scale describes augmented reality, where physical space is augmented with digital information, and augmented virtuality where information from physical space is inserted for example into a CVE. Implementations of both these two will be considered briefly in turn.

Feiner et al introduce an augmented reality application for outdoors (Feiner, et al, 1997). The Touring Machine presents location-based navigational information to visitors to a university campus inside a head-mounted display that is driven by a mobile computer carried in a backpack. Anabuki et al place virtual objects and a conversational agent inside a physical environment (Anabuki, et al, 2000). Both are fully interactive and are rendered to people present in this space via a head mounted display. Augmented Surfaces, introduced by Rekimoto et al, allow people to extend the desktop computer interface on to physical surfaces around them (Rekimoto and Saitoh, 1999). For this purpose graphical content on tracked portable computers is linked for example to graphical content projected directly on to a table.

A different route is followed by research into augmented virtuality where information taken from physical space is added to virtual space, often in the form of video imagery. Three systems have been reported on, all in the same year, that map live video onto the geometry of an avatar embedded in a CVE (Han and Smith, 1996, Nakanishi, et al, 1996, Reynard and Benford, 1996). Just like in an ordinary CVE, people can move around virtually, form groups and have conversations with each other, whereby the level of video and audio quality can be controlled as a function of the distance between people. The video itself provides a much better rendition of facial expressions and some information about the physical context of a person than CVEs. The two strands introduced above, Augmented Reality and Augmented Virtuality, clearly place emphasis on one of the spaces, physical and virtual space respectively. Mixed Reality as an overarching concept makes no such emphasis and this review of relevant technologies finishes with a technology that conceptually occupies the middle ground of Milgram's virtuality continuum: the Mixed Reality Boundary.

The Mixed Reality Boundary (MRB) technology joins a physical space to a virtual space with a two-way transparent window (Benford, et al, 1998). Its physical side is implemented as a fixed, large screen projection with a camera attached to the screen, speakers at the sides and a microphone. Within the CVE it is represented as a fixed piece of geometry to which the live video taken from the physical camera is mapped. People on both sides of the MRB can communicate across the open audio and video connection (see also Figure 8 and Figure 9). Through the position of camera and microphone in physical space, the physical context of its

location can be transmitted. In turn, the size of the projection and its resulting presence in a physical space result in a sense of connection to the CVE that is not possible with the desktop set-ups typically used. Benford et al also suggest the use of multiple MRBs to create tessellated Mixed Realities, where multiple physical and virtual spaces are connected to each other. Reynard has demonstrated the construction of a static example of such a Mixed Reality (Reynard, et al, 1998). The authors concentrated on technical aspects of their implementation but did neither explore its architectural implications nor the social interaction taking place within their approach. Finally, Koleva has concentrated on the properties of the MRB itself discussing its permeability, situation, dynamics, symmetry and representation (Koleva, 2001).

## ***2.4 Research opportunities***

This literature review has discussed architectural configurations and their relationship to co-presence between its inhabitants, the dynamics of architecture, the nature of the relationship between telecommunications and architectural topologies and a selection of specific communication technologies relevant in this area. This material has opened up a number of areas that are in need of further investigation.

Firstly, it is clear that communication technologies allowing social interaction at a distance have been studied in depth. Although spatial approaches have been introduced to some of these, no direct attempt has been made to apply architectural theory to their development or explore the architectural potential of these technologies. Secondly, it has been shown that certain aspects of architecture can be made more dynamic, and dynamic virtual architecture has been proposed. However, through this review it has become clear that architecture has remained topologically static, although it exists in an environment that is socially and technologically very dynamic. Finally, it has been pointed out how architecture structures co-presence as the prerequisite for awareness and social interaction, and how the rules and norms of society structure architecture in turn. At the same time, telecommunication technologies allow simulated co-presence at a distance and they have clearly influenced the structure of the urban environment. In response, it has already been suggested that architecture should be investigated in terms of its relationship to and extension into the digital domain. As a review,

the above is naturally mostly based on existing work and practices. Overall, it therefore lacks a theoretical dimension that would tie together the emerging field of MRA, and this is what will be presented in the following chapter.

# 3

## Framework of Mixed Reality Architecture

Mixed Reality Architecture (MRA) has been defined for this research as an approach to Mixed Reality with a distinctly architectural perspective. MRA links and overlays multiple physical and virtual spaces in a dynamic way in support of social interaction between people who are not physically co-present, providing them with a shared spatial framework. MRA as a phenomenon therefore consists of physical spaces, virtual spaces and the technological means to link the two. In this context, virtual spaces are understood to be artificial spaces generated by a computer that aim to introduce a three-dimensional spatial metaphor.

While the review of the literature in this field has shown that there is extensive material covering the separate elements of an architecture that spans physical and virtual spaces, to the author's knowledge there is no coherent framework that could describe this type of architecture, Mixed Reality Architecture, in its en-



tirety. In addition to this, work with related demonstrator projects (Koleva, et al, 2000, Schnädelbach, et al, 2002) and a pilot study in this area (see chapter 5) had already uncovered a number of issues that appeared critical for the future development of this approach.

Therefore, a theoretical framework of Mixed Reality Architecture seemed essential for its future extension and development. This framework describes the field of possible architectures that emerges, when physical and virtual spaces are combined with a particular regard for the resulting topological flexibility, access to its parts and the levels of co-presence that can be established in principle. It draws on the literature provided in the previous chapter but new material is also introduced to complete the picture where appropriate. The framework is intended as a resource particularly for architecture constructed in this area but also for the development of Mixed Reality systems in general. It has been divided into three categories. These are concerned with the qualities of physical and virtual three-dimensional spaces, the qualities of links between a combination of the two and the qualities of the resulting architectures.

When developing this framework, one key concern was to keep it theoretical in outlook, independent of any technological implementation, because it was felt that the consideration of any particular, currently available interface technology would undoubtedly influence the main argument. At the same time, it was clear that the only way three-dimensional virtual spaces become accessible to us is through technology. It is suggested here that one way of dealing with this contradiction is the assumption of the 'ideal' interface, an interface that is entirely transparent to us, so that the experience of virtual spaces becomes indistinguishable as much as possible from that of physical spaces.

Such an interface has been described by Deutsch in a provocative thought experiment. In *Fabric of Reality*, Deutsch discusses the structure of reality drawing on the scientific discoveries of the 20<sup>th</sup> century (Deutsch, 1998). The author argues that our experience of virtual space does not have to be seen as entirely different from that of physical space, since our sense organs are clearly not the only determining factor in what we perceive of the space around us. Our brains play the determining role, in effect taking different stimuli from physical space and rendering or assembling them into a coherent whole.

*"What we experience directly is a virtual-reality rendering, conveniently generated for us by our unconscious minds from sensory data plus complex inborn and acquired theories (i.e. programs) about how to interpret them." (Deutsch, 1998)*

While not necessarily adopting this representational view of spatial cognition, the thought experiment that Deutsch introduces in this context has proven useful for thinking about the spatial possibilities that exist in MRA. Deutsch describes an interface capable of rendering virtual environments directly to our nervous system bypassing our sense organs (Deutsch, 1998). In science fiction, this has of course been suggested previously, most notably in *Neuromancer* (Gibson, 1984), but here Deutsch uses this type of interface as a vehicle to discuss the possibilities of VR in principle. It would require sensors that measure a person's actions directly from their nervous system, output devices that feed back the environment's reactions as nerve impulses and a computer that controls the process and synthesises the environments. Coming from an entirely different angle, Wilson discusses the perceptual principles that give rise to the possibility of such an interface in the context of using virtual environments in spatial learning research (Wilson, 1997). Users of such a system could then decide whether they want to experience predominantly physical space, predominantly virtual space or a mixture of the two according to their requirements.

Such an interface clearly does not exist at present and no claims are made here about its future availability. However, its assumption allows the discussion of the limits of what can be experienced in physical and virtual spaces independently of the capabilities of currently available interfaces to virtual spaces. These limits then depend on the capabilities of our sense organs, nervous system and brain, and not on the particular interface technology used.

However, as will be discussed, this type of interface comes with its own constraints that cannot simply be ignored. In particular, it is individual in its nature, providing inhabitants of MRA with their own access. Indeed, as it is designed to be as transparent to us as possible, it is much more comparable to our own sensorium than to typical interface technology, since our own sensorium also gives us individual access to the shared physical space. Furthermore, for any particular application of the framework to an architectural design that is constructed at present or in the near future, a specific interface technology will have to be chosen and again its particular constraints will have to be considered. In what follows,

physical and virtual spaces, links between those and the architectures that can be created from these basic elements will be discussed.

### **3.1 Spaces**

Architecture modulates the properties of the spaces around us. It expresses these spaces by representing their boundaries with tangible and visible substances. How boundaries and surfaces are conveyed to us depends on our perception, which is in turn based on our internal and external senses. Internally, the kinaesthetic sense and the sense of equilibrium both provide stimuli regarding the relationship of our bodies to the space around us and our movement through it. Externally, the senses of sight, hearing, touch, taste and smell deliver information about the boundaries that define architecture for example in terms of restrictions they impose on our movements. As Deutsch has argued, the output of our sense organs is then synthesised according to inborn and acquired models (Deutsch, 1998). Arguably, the above can hold true for the experience of virtual as well as physical spaces when the 'ideal' interface, as suggested by Deutsch, is assumed (Deutsch, 1998). At the same time, there are important limitations to the experience of physical and virtual spaces.

This section explores physical and virtual spaces in terms of their flexibility, what types of access we are granted to them, co-presence between people and the limits of experiences within them.

#### **3.1.1 Flexibility of spaces**

Physical spaces, or more precisely the physical enclosures of spaces, change over time. Boundaries in nature, for example the sides of a rock gorge, erode slowly; physical buildings are continually re-adapted to new uses (Brand, 1994) and sometimes even moved to new locations (BBC, 1999). Radical shifts in these patterns are generally only caused by revolutionary events (e.g. the industrial revolution, wars, natural disasters). In certain cultures, considerable use is made of spatial adaptation, as for example with the sliding panels in the traditional Japanese house; however, this is not common in most traditions and even the change in this context is framed by what has been permitted by the architect.

These changes to physical space are however relatively expensive in terms of time as well as cost. Therefore, it can be argued that the flexibility of physical space is highly limited by the stability and longevity of its enclosures. Equally, the properties (e.g. materials) of the bounding surfaces to space are comparatively inflexible and it requires considerable effort to change them. With their permanence, affordances that boundaries might offer to people become perceptible to us allowing us to judge their properties from a distance (Gibson, 1979). For example, the fact that a wall is made from concrete clearly informs us that we cannot traverse it.

Modernist architects, who found this inflexibility too restraining have dealt with this in at least two ways. They have concentrated on the movement of inhabitants or observers through space and therefore designed spaces to be continuous and fluid. But they have also started to consider the mobile 'architectures' of trains, planes and cars (van de Ven, 1987). More recently, architects have applied computers in the form finding and production processes. This has led to much more fluid and responsive buildings such as the freshH2O eXPO project by NOX (Zellner, 1999). However, these buildings remain spatially static in terms of their topology since the relationships between their internal spaces or their spatial relationship to the exterior does not change.

In contrast to physical spaces, virtual spaces can be designed to accommodate rapid changes in extent and position to suit changing requirements. Novak describes "Liquid Architecture" as being "designed as much in time as in space, changing interactively as a function of duration, use, and external influence" (Novak, 1995). This architecture is an attempt to overcome conventional, very static architectural concepts by making use of the inherent flexibility of virtual environments. In addition to this, false affordances (Gaver, 1991) can be introduced that 'misrepresent' the actual properties of virtual boundaries by for example applying unexpected material properties. A virtual polygon that can be crossed could be textured with a concrete texture or virtual boundaries could be made invisible. Virtual environments enable architects to consider not only the movement of people through space but also the movement of spatial elements themselves, animated or even animate in relation to time as a vital element of the design. However, are virtual environments really as flexible as they seem? In general, they are perceived as allowing users to change any of their aspects. If not

restricted by the architects of the environment, virtual objects can be moved at will to any position and can be passed through by other people as well as other objects. In fact, the lack of appropriate restrictions of this flexibility can lead to problems for people in terms of their ability to interact with each other and the environment (Purbrick and Greenhalgh, 2001). However, there will always also be limits to the flexibility of any given environment as defined by the underlying computational infrastructure. This infrastructure will allow the change of certain aspects but might prevent or at least make rather difficult the change of others. For example, systems do not typically enable people to change the spatial coordinate system of an environment or its system time. In comparison to physical reality though, virtual environments can allow much greater flexibility in their topology, and this property will be exploited for the construction of MRA.

### **3.1.2 Access to space**

Our bodies fully access physical space. This includes our sensorium but also all our physical needs (e.g. nutrition, rest, etc.). Indeed our bodies as well as our sensorium are spatial themselves, having their own spatial extent and constraints in the same framework and they are what gives us access to the experience of space in the first place, through our sensorium, nervous system and brain (Franck, 1995, O'Keefe and Nadel, 1978). As a result, physical bodily movement must always result in immediate movement in and through space.

Access to space is democratic in principle, meaning that space of itself does not allow access for one person and deny it to another; people present in the same portion of physical space will perceive almost the same underlying data, while they might well perceive a different mediation of this data as affected by their own perception (e.g. the reported different in colour perception between men and women (Verrelli and Tishkoff, 2004)). In practice, the picture is quite different, though. The physical and mental abilities of individuals will govern their access to certain areas (e.g. a person in wheelchair not being able to climb stairs) and the rules embedded in society also restrict access to portions of space to certain groups of people. Nevertheless, there are spatial regions like public space for example that are accessible to everyone, and here there is potential for social interaction between people. Finally, in physical space, we are represented by our own body to everybody. Furthermore we can only have one representation at a

time, discounting technological means, such as tele-embodiment, a technological concept that aims to provide awareness of remote physical spaces by way of allowing people to control a robot in such a space (Paulos and Canny, 1997).

In contrast to the above, while virtual space does allow full access to all our senses, when the use of an interface directly wired into our nervous system is assumed, it does not provide full access to our bodies. Therefore, the satisfaction of physical needs (e.g. food) might be simulated but cannot be fulfilled and similarly we always remain bodily present in physical space, susceptible to physical events and distractions (Bowers, et al, 1996), while we might not be consciously present in that space. Our physical body has no extent in virtual space and does not become part of it. The movement of our limbs does not in general map immediately on to movement in virtual space, although there are numerous interfaces that go some way in that direction. For example, Darken et al present an omni directional treadmill and Iwata et al present a walking interface that incorporate, roller skate like shoes that slide in any direction (Darken, et al, 1997, Iwata and Fujii, 1996). In both cases the user remains in one spot physically, but his physical walking movement is translated into virtual movement.

Another defining property of virtual space is that it is possible to tailor the level of access to it. The experience of the same virtual space can then be designed to appear different to different groups of people, for example, when certain elements of it are only made visible to certain individuals (Greenhalgh, et al, 2000). Instead of providing public access to all aspects of virtual space, the experience then becomes private and individualised. In addition and in a very similar fashion to physical spaces, virtual spaces can also be public or private in their entirety. Boundaries between public and private virtual spaces then control who has got access to what. Finally, entering virtual space requires us to adopt an electronic representation, whether that is directly derived from our own physical appearance (Akimoto, et al, 1993) or complete phantasy (Activeworlds, 2004). It clearly is also possible to have multiple representations at the same time as Mitchell has observed (Mitchell, 1995).

### **3.1.3 Co-presence**

As we are spatial ourselves, space is the prerequisite for co-presence, at least as long as it is unmediated by technology. All physical encounters and social inter-

action take place within space. We also use space to control and regulate social interaction once it has been established, in terms of how much space we leave between individuals in a group according to the situation that the interaction takes place within (Hall, 1966). As physical spatial configurations are not very flexible, they provide society with a more or less stable base to grow within both spatially as well as socially. Physical space allows individuals to understand the spatial structure around them and what Mitchell calls 'civic legibility' (Mitchell, 1995).

The development of virtual spaces has been driven by the aim of supporting co-presence and therefore social interaction in a similar way to physical space. Benford et al, in their analysis of spatial approaches to CSCW enumerate a number of key issues: the provision of peripheral awareness of the actions of others; the realisation that informal interactions, as often generated by chance encounters, are an important part of co-operation; and the benefits of providing people with a sense of place since many online co-operative activities are distributed over a number of sessions (Benford, et al, 1996). Indeed, often the aim has been to simulate the properties of physical space directly and make similar use of it in the virtual environment. For instance, the spatial model of interaction as introduced by Benford et al imposes rules on the ability of people to communicate with each other that are based on the spatial proximity of their virtual representations (Benford and Fahlén, 1993). At the same time change in virtual environments is inherently faster than in physical space, simply because those are developed in a relatively short time scale. In addition, virtual spatial configurations can be designed to change rapidly as has been suggested previously. In contrast to physical space, a society existing in such a truly flexible spatial topology might be confronted with a shifting spatial arrangement rather than a stable basis, which would presumably be difficult to navigate and comprehend, depending on the speed at which it changes and who controls those changes.

#### **3.1.4 Limits to experience**

There are also clear limitations to our experience of reality, whether physical or virtual. In physical spaces, these are imposed not only by the laws of physics but also by the limitations of our sense organs. For example, gravity prevents us from experiencing weightlessness on Earth without the help of technological means, nor can we perceive infrared light or the rotation of our planet because our sense

organs are incapable of perceiving these phenomena. Finally, physical space does not permit the experience of somebody else's experience.

Deutsch points out that this also limits virtual space in principle as only experiences that we can sense can be successfully rendered (Deutsch, 1998). Therefore, our experiences generated by virtual reality can be outside the bounds of what is possible in physical space (e.g. weightlessness) but virtual environments cannot guarantee the reproduction of internal experiences (e.g. pride) and certainly cannot reproduce illogical experiences (e.g. unconsciousness) since we are incapable of sensing those. The reasoning behind this argument is that it is logically not possible to sense that we do not sense anything just as it is impossible for us to sense stimuli we do not have sense organs for. Therefore, our physical body remains, and probably always will remain, the relevant starting point for a discussion of what virtual reality is capable of simulating and what not. In addition, possible experiences are limited by the rules that govern a particular virtual environment, whatever those rules might be. For example, many online role playing games do not permit people to harm each other's representation. However, virtual space will allow the experience of others' experiences at least to the extent of the relevant sensory data being replayed in exactly the same form to more than one person. At this point it is worth briefly summarising the properties of physical and virtual spaces, the two main components that MRA consists of. The following table lists all four properties that have been discussed: flexibility of spaces, access to spaces, co-presence and limits to experience. It is important to point out that the presentation in this table clearly required a certain level of abstraction, but the full text above provides all the details.

<i>Physical Spaces</i>			
Limited Slow	Full bodily	Full	Limited by Physics and internal sense organs
<b>Flexibility</b>	<b>Access</b>	<b>Co-presence</b>	<b>Limits to experience</b>
Full Rapid	Limited to senses	Simulated	Limited by internal sense organs
<i>Virtual Spaces</i>			

**Table 1 Physical and virtual spaces**

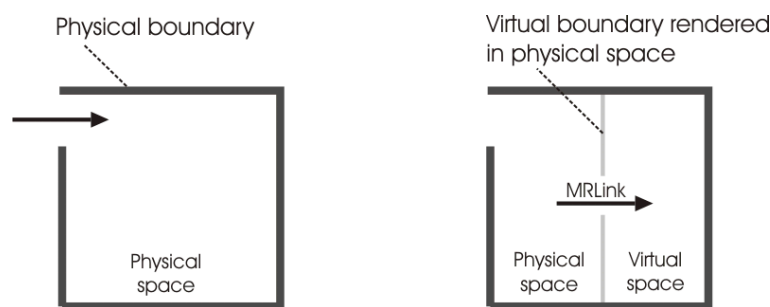


### 3.2 Mixed Reality Links

Following the description of the qualities of physical and virtual spaces above, this section outlines the properties of the links required to join spaces into Mixed Reality Architecture. Mixed Reality Links (MRLinks) are defined here as links between one physical space and one virtual space. A previous analysis of the boundary between physical and virtual environments (Koleva, et al, 1999), but also a fresh look at links within physical and virtual architecture have both served as starting points for the following account of MRLinks.

At the most basic level, the link between physical and virtual space is created by the set-up of virtual space itself, as there needs to be an interface for the input and modification of the underlying data. Therefore, through the mere existence of virtual space the two kinds of space are always linked by technology. However, how this link is conveyed to us is a question of design. We are accustomed to understanding links between spaces as gaps in the boundaries that separate them (Simmel, 1909). Mixed Reality Links can be represented in a similar fashion.

In physical space, a link to virtual space might appear as a gap in a virtual wall, creating an opportunity to cross. That wall in turn would be rendered to our nervous system as a representation of a boundary between physical and virtual space. Previous work by the author has demonstrated the principles of this relationship with the technology that was available at that point (Koleva, et al, 2000). Crossing this link (see section 3.2.2 for what limitations exist) would mean that our sensorium then predominantly perceives stimuli from within virtual space, as this is what is now rendered to us. Figure 1 illustrates a physical space with one physical door as access. The graphic on the right then shows the same space with an MRLink across a virtual boundary that has been rendered to appear in physical space.



**Figure 1 A Mixed Reality Link rendered to appear in physical space**

A link back across would also be represented to us as a gap in whatever denotes the boundary to physical space. Boundaries and links between physical and virtual could then be designed and perceived just like ordinary architectural elements (e.g. walls, doors); their affordances in terms of their traversability would have to be made clear in design.

This section explores Mixed Reality Links in terms of their flexibility, what types of access we are granted across them, co-presence established by them and possible targets.

### **3.2.1 Flexibility of links**

Mixed Reality Links are highly flexible in terms of quality and mobility. Which spaces are linked to which can be changed and adapted quickly, given the right access control (Benford, et al, 1998). The quality of link targets will be discussed in section 3.2.4. In addition, a link between one particular physical space and one particular virtual space can also move its position, in effect reconnecting the same two spaces in different locations over a period of time (see Figure 5) (Schnädelbach, et al, 2002). These changes in terms of what is being linked to and where the link is located can be controlled by individuals (e.g. the creation of new virtual portals in Activeworlds (Schroeder, et al, 2001)) or by the overall 'owner' of a particular MRA (e.g. the set-up of portals as part of the overall design by the designers of an environment (Craven, et al, 2001)).

### **3.2.2 Access across the link**

In terms of what access they provide, Mixed Reality Links have very different properties from links between separate physical spaces. Our physical body and its physical needs cannot cross into virtual space, regardless of the type of interface we might be using (see section 3.1.2). At the same time, our internal and external sensorium can be made to perceive virtual space exclusively, which is dependent on what is being rendered to us. Different links can then allow different levels of access, just like links between physical spaces allow the perception of different aspects of the space on the other side (e.g. a curtain versus a glass door).

An intrinsic property of virtual spaces is that content can be tailored to individuals, and this is no different for MRLinks. So it could well be that a designer

chooses to restrict access to an MRLink to a certain group of people or make it available to everyone who is physically or virtually close by. This is however a matter of design and not inherent to MRLinks as such. If they have not been 'individualised', links are part of the same spatial framework as any other object or indeed person, and crossing links as well as the associated changes in status become visible to everyone. An important part of 'civic legibility' (Mitchell, 1995) is re-introduced into networked social interaction, as now it becomes possible again to understand who is accessing what.

MRLinks could also be used by their owners, just like links within physical space, to exert control over the behaviour of people, when certain routes within the MRA are made available or are closed off. At the same time the owner's own control might well be limited by whoever owns the underlying infrastructure.

As already mentioned, crossing a link requires us to take on one or multiple representations in the space to be entered. When entering virtual space this representation would be an avatar. When entering a remote physical space (i.e. all physical spaces besides the one the person under consideration is physically present in) a physical proxy can take the role of the avatar (Koleva, et al, 2000). In this context it is worth considering the effects of 'leaving' a representation or indeed your own body in a particular space, to be able to perceive another space. Once a person perceives virtual or physical space exclusively, their representation on the respective other side might be designed to portray that they are unavailable there (Benford, et al, 1995) or in the case of a physical body they might be protected from adverse influences (Koleva, et al, 2000).

### **3.2.3 Co-presence**

MRLinks can be set up to allow co-presence between people in physical and virtual spaces, which is particularly relevant when the people concerned are physically remote from each other. Then two or more people can meet in a shared mixed reality environment. However, an interface linked into people's nervous systems would allow MRLinks to be entirely individual. Not only could MRLinks be visible and accessible to only one person, but even if they were accessible to a group of people, they might link into a shared or a private virtual space, just like points of access between physical spaces. Therefore, some people in that group might have permission to cross the link, while others cannot, when

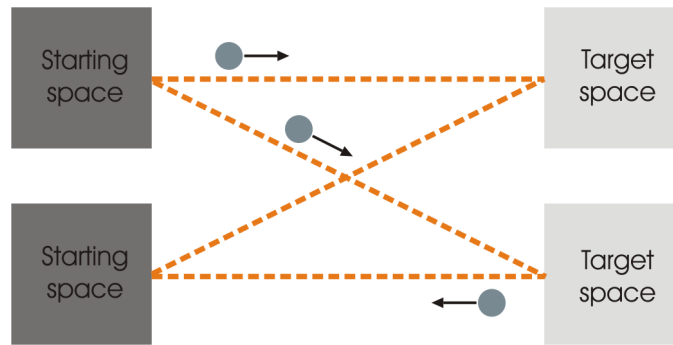
those have no right to enter the linked space. The target of a link further influences this, as will be shown in the following section.

Only when MRLinks and the linked spaces themselves are available to more than one person, can co-presence be achieved, in that MRA provides a common spatial framework for social interaction across physical and virtual spaces. To achieve the greatest potential for co-presence, MRLinks need to be situated in the public domain. They could be conceived as moving physically as well as virtually, but they would have to be available to everyone either physically or virtually close by. To reduce the potential for co-presence, MRLinks need to be made private instead as already discussed.

### **3.2.4 Targets of links**

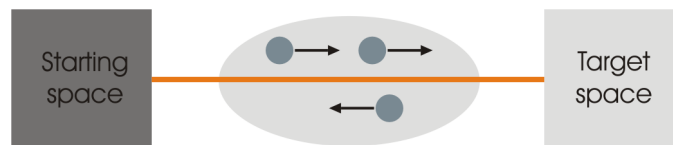
In the context of this research, the target of a Mixed Reality Link is always another three-dimensional space. When starting from physical reality, this can be any virtual space in the MRA that can be rendered to a particular inhabitant. From within virtual reality, a target can be any physical space in the MRA. Significantly, there is a fundamental difference between the physical space that an individual starts off in and all other physical spaces, since only the former can be entered fully with our bodies as outlined in section 3.1.2.

The target of a link can be defined by an individual or by the spaces that are linked. Both will be considered in turn. In the first case, starting points and targets are only linked by the event of crossing. They could be described as independent portals and each individual entering a specific portal might link to a different target. Evidently, this would have consequences for establishing co-presence, since crossing a link together from a shared, public space does not guarantee co-presence once the link is crossed - or during the journey, for that matter. Figure 2 illustrates this relationship with three people crossing between two starting points and two targets. They do not encounter each other during the journey. In this latter aspect this type of MRLink is similar to the hyperlinks of the Internet.



**Figure 2 Crossing between independent starting spaces and target spaces**

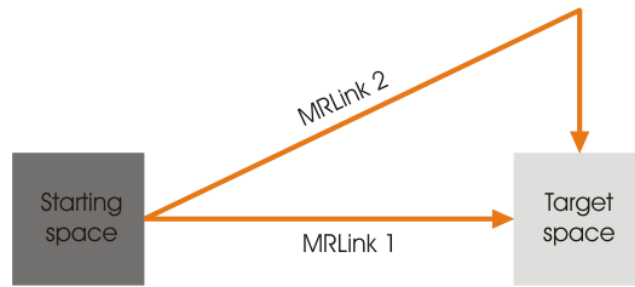
In the second case, over its life time, each link could be defined by its position or starting point in a specific space and its target in another specific space. Once the starting point or target changes, a new link is established and the original link ceases to exist. Each person crossing this type of link would traverse to the same linked space, maintaining co-presence with another person during and after crossing it. Figure 3 illustrates this second relationship with three people crossing between on starting space which is coupled to one target space. They encounter each other during the journey.



**Figure 3 Crossing between coupled starting space and target space**

Which one of these types of link is chosen for an MRA is a matter of design. They might well occur together, which opens the question, how their affordances can be made evident to inhabitants of an MRA.

MRLinks can also be segmented, meaning that the target of a particular link can be accessed in more than one way (Benford, et al, 2001). The segments of a target can then have different properties from each other. As an example one could envisage an MRLink that provides two views from physical space into the same virtual space, one being aligned vertically and the other horizontally so as to be able to observe different aspects of the other space at the same time, possibly even at different scales. Figure 4 illustrates this relationship.



**Figure 4 Segmented MRLink**

In addition, from within each space there might well be a number of targets that a person could link to, depending on whether environments and links have been made available publicly.

In terms of time, targets of a Mixed Reality Link can be accessed instantly, bar the physical limitations of the hardware used both locally and across the network; but accessing parts of the MRA that are more remote in the topology can be designed to require time for virtual travel. In addition to the above, Mixed Reality Links can also transform the target temporally when they link to a recorded virtual space for instance, changing the interaction from being synchronous (within technical limits) to being asynchronous (Deutsch, 1998) (Greenhalgh, et al, 2000).

At the end of this section it is once again worth briefly summarising the discussion in a tabular way. The following table lists the properties of Mixed Reality Links linking physical and virtual spaces. The table presents all four categories that have been discussed: flexibility of links, access across the link, co-presence and targets of links.

<i>Mixed Reality Links</i>			
Flexibility	Access	Co-presence	Targets of links
Targets Position	Limited Individualisable Exertion of control Required representa- tions	Depends on level of access and nature of target	By individuals By spaces Segmentation

**Table 2 Mixed Reality Links**

### ***3.3 Mixed Reality Architecture***

The final section of this framework aims to set out the concept of Mixed Reality Architecture as a configuration of physical and virtual spaces joined together by

Mixed Reality Links. We perceive MRA in its entirety through our perception of its constituent parts: spaces and links. Their properties tell us about the qualities of the overall architecture and we perceive these properties with whatever part of our sensorium we have access to in different segments of an MRA. At the same time, the architecture takes on properties as a whole that can only be understood by considering more than its elements and by movement through the MRA, not unlike the physical only architectural configurations that have been discussed by Hillier (Hillier, 1996) (see section 2.1 for details). As in physical or virtual architecture, this requires exploration, even multiple explorations, for people to be able to build up an understanding of the overall topology. In contrast to physical architecture however this could potentially be relatively difficult, since the topology is not stable as will be discussed in this section.

### **3.3.1 Flexibility of MRA**

The overall structure of MRA can be designed to be very flexible. Links can be established as well as removed from an MRA very rapidly. A person aiming to adapt an MRA to their needs might trigger this change, or it might be triggered automatically by certain events. In addition to the above, parts of the structure can also move position. As has been noted previously this type of adaptation also effects the overall configuration as the permeability of the configuration changes as the relationships between different spaces change (Hillier, 1996). Of course this is already possible in physical architecture, although to a limited extent and at a slow pace. With the addition of virtual spaces and links into the equation, this change in permeability becomes much more of a distinct possibility and can also occur more rapidly. However, MRA as a whole is ‘anchored’ in some respect from the perspective of each person. The physical space they started off in is always the one they will come back to, given that no physical travel is involved.

### **3.3.2 Access to MRA**

Effectively, people have different degrees of access to different parts of an MRA. Firstly, full bodily access is only given to the space that was physically entered, while other areas can be perceived to varying degrees. Secondly, depending on the type of link employed, parts of MRA can be experienced only by individuals or certain groups, while other parts are available publicly. On the one hand, this

is the result of control exerted at each link, effectively barring access completely for particular groups. On the other hand, it is caused by the ability to render parts of the virtual structure, spaces as well as links, selectively to individuals or groups. Both the above would result in an individualised outlook on MRA, in terms of which parts of it are accessible. This might seriously impede individuals or groups of individuals having a common frame of reference for social interaction, even if they are close to each other in the MRA. At the same time, if a common spatial framework is desired, it can be established by the architects of an MRA.

What is accessible also depends on who controls the overall topology including its infrastructure. It is quite conceivable that one person or organisation has overall control over an MRA, similar to a company having control over its own intranet. However, if the infrastructure was constructed on the basis of open protocols and standards, each individual piece of MRA could be linked to any other MRA. This would make effective overall control impossible, very similar to the current structure of the Internet, although even there a row has recently erupted over who should control the management of domain names and traffic routing, two fundamental underlying features of the network (BBC, 2005). In this context, it is more likely that ownership of and control over the 'MRA of MRAs' would emerge to be distributed between the owners of its constituent pieces.

### **3.3.3 Co-presence in MRA**

Co-presence within MRA does not occur in an unbounded, abstract spatial expanse but space has a certain structure provided by its architectural topology as with physical and virtual architectural topologies. As Hillier et al argue when discussing physical architecture, this structure, within as well as outside buildings, has certain effects on co-presence since it structures movements, encounters and avoidance patterns of otherwise discrete individuals prior to the effect society itself has (Hillier and Hanson, 1984). This structuring effect can be generative, when it encourages encounters between people, opening up the chance for social interaction between strangers. At the same time, the spatial patterns of architecture are clearly structured by society as they are laid out according to certain rules that differ from one society to another. These patterns as affected by the



underlying social rules in turn make the existence of society visible and make its spatial form recognisable.

Arguably, virtual spaces are equivalent to physical ones of similar topology in terms of their generative and conservative effects on social interaction when navigation is simulated to be comparable to that in physical space (e.g. flying is not allowed). Indeed, movement through virtual space, which provides the chance for encounters and therefore the potential for social interaction, can be shown to be statistically similar to movement through an equivalent physical space (Conroy, 2001).

And again in a way copying physical reality, the overall topology of a virtual environment is governed by the rules that exist within it. Alphaworld, a part of the Activeworlds set of environments (Schroeder, et al, 2001), might serve as an example here. Inhabitants are granted certain property rights. They can claim land, build on that land and exert some control over it. It might be said the ownership and control over space is therefore emergent. Over time an individual might accumulate control over an increasing area of virtual space. However, overall control over space, including individually 'owned' land and buildings, ultimately lies with the owner of the computational infrastructure in this particular case.

How MRA affects co-presence of people living within it depends largely on its underlying topology. Is a topology chosen that will allow people to share MRLinks to a shared public space, or are people in effect prevented from meeting within MRA, by providing private MRLinks and spaces? This is ultimately about design choices making one or the other possible. Equally, whether MRA can make visible the networked, interconnected condition we live in by giving it a recognisable spatial form also depends on which form it takes. The role of MRA in establishing co-presence and its role in providing spatial form to networked society are two major areas of research that are being investigated in this thesis.

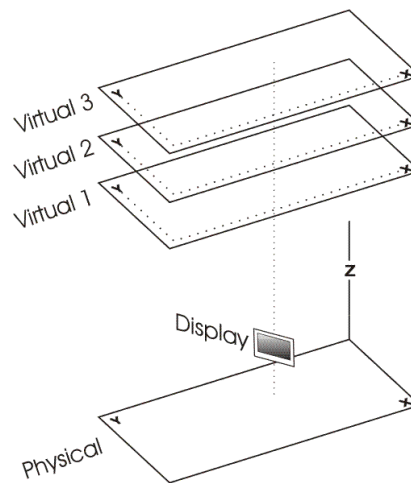
### **3.3.4 Topology of MRA**

The overall topology of MRA is defined by the underlying topologies of physical and virtual spaces as affected by the relative position of MRLinks within them. There can only ever be one physical spatial topology, that of physical reality, while there might be a number of virtual topologies available at any given

MRLink. Two distinct relationships between physical and virtual spaces can exist: the spatial relationship between them can be defined or they can have no spatial relationship to each other. These two cases will be discussed in turn.

#### **3.3.4.a *The spatial relationship is systematically mapped***

With physical reality as the base layer and spatial reference, virtual topologies are stacked or layered and spatially fixed (see Figure 5). For the full exploration of the topology of such an MRA, an MRLink would have to be physically mobile (user-centred) and its movement tracked. By moving with the MRLink, different parts of the topology of MRA are then explored in parallel. The Augurscope, a mixed reality interface for outdoors, is a good example in this context (Schnädelbach, et al, 2004).



**Figure 5 Layered spatial topologies**

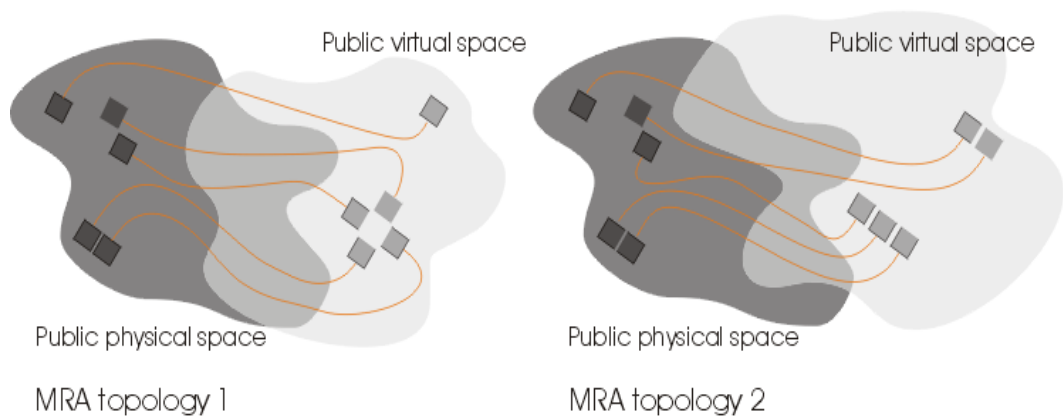
Which layer of data is accessed can be chosen by the user, the developer or both as already discussed in section 3.2.4. Also, it might be possible to access more than one virtual layer, if that has been permitted.

One of the most common approaches to Mixed Reality, Augmented Reality (AR), is based on this type of spatial topology (Anabuki, et al, 2000). In AR the topology of physical space is typically applied to virtual space. Indeed, one of the main research challenges in this area is to effect a registration as exactly as possible between physical and virtual environments. AR can be described as one extreme of a spatial relationship that is systematically mapped. Each point in physical space finds an equivalent point in virtual space, which replicates the coordinate system of physical space. It is also conceivable that spatial and temporal

transformations can be introduced in the MRLink so that spatial transformations in physical space are translated into virtual space, but not necessarily in the same coordinate system or at the same time (see also section 3.2.4).

### 3.3.4.b *There is no spatial relationship*

Physical and virtual spaces do not have to have a spatial relationship to each other. Virtual spaces can have their own co-ordinate system and can change position in relation to physical space, if such a relation was ever specified. In this case an MRLink between physical topology and virtual topology is physically static (e.g. desktop computer), or at least its physical position has no influence on which part of a virtual space is accessed (e.g. handheld computer without tracking). Only the virtual part of this type of MRLink moves and its physical and virtual positions are de-coupled. The figure below shows how the same interfaces to virtual space link to different parts of a virtual space, while remaining physically static.



**Figure 6 No spatial relationship**

Again, which virtual space can be accessed from any given interface can be decided by the user, the developer or both and it might well be possible to join several spaces from the same MRLink, if that has been permitted. In contrast to the first type, multiple interfaces can be in the same virtual position.

This topology is most commonly employed for desktop 3D applications like for example Activeworlds (Schroeder, et al, 2001). The original Mixed Reality Boundary is a special case of this approach, since it was designed to be physically and virtually static (Koleva, et al, 1999), but it is conceivable that it might be made virtually dynamic in a similar way to a desktop interface. In addition to the

above it also allows a link back into other physical spaces. This means that the overall topology of MRA changes with the virtual positions of its MRLinks. In terms of the experience for inhabitants of MRA, the underlying physical topology is in effect warped. Figure 6 demonstrates this relationship. A person in physical space can interact with people in different other physical spaces across the shared virtual space. Crucially, with the virtual position of MRLinks changing within the MRA, the overall topology also changes, a concept that will be exploited in the implementation of MRA.

### 3.4 *A theoretical basis for further research*

This chapter has provided an overview of the constituent parts of MRA, namely physical and virtual spaces and MRLinks between them. This resulted in a description of abstract MRA itself and its properties. As before, this can be summarised in a tabular way. The following table presents all four categories that have been discussed: the flexibility of MRA, access to MRA, co-presence in MRA and the topology of MRA.

<i>Mixed Reality Architecture</i>			
Flexibility	Access	Co-presence	Topology
Varies across the MRA, determined by the properties of the constituent physical and virtual spaces and Mixed Reality Links (as discussed in sections 3.1 and 0)			Determined by relationship of physical and virtual spaces: Mapped spatial relationship No mapped spatial relationship

**Table 3 The properties of Mixed Reality Architecture**

At this point, an example based on an existing Mixed Reality system will help to put the framework into context and demonstrate its application. Second Life, a very popular 3D online environment (Linden Research Inc., 2006) is usually accessed through a standard desktop PC. It allows its inhabitants to build buildings and to trade objects of different kinds. Social interaction occurs through text chat and the experience is customisable to a certain extent. For this discussion, it is assumed that Second Life can be accessed in full 3D on a small portable device such as a mobile phone. Therefore, physical spaces and virtual spaces are connected

via a mobile Mixed Reality Link and in what follows, the framework of Mixed Reality Architecture will be applied to this example. Cutting across the framework, flexibility, access and co-presence will be considered first, before discussing the limits to the experience, link targets and the topology of the overall structure:

**Flexibility:** In contrast to physical space, the spatial structure of Second Life is relatively flexible in that buildings can be put up and taken down rapidly and inhabitants have considerable control over this process. However, virtual structures do not tend to be animated but anchored to a virtual location. The overall flexibility described here is then restricted by the organisers of the environment, who limit where inhabitants can build and who has control over what. Additionally, the end-user has got full control over the target and the position of the Mixed Reality Link. By turning the mobile phone on and off, the end-user establishes and breaks this link. They also control which virtual space the target of a link is, and which physical space they link from, as the link itself is physically and virtually mobile.

**Access:** Access to virtual space is heavily limited by the mobile Mixed Reality technology and the interface that Second Life provides. The only bodily sense that is supported is sight, with communication occurring over text chat. The screen size of a mobile phone is also very small, which limits the visual sense of immersion. This access is also individualised in the sense that an inhabitant uses their own mobile Mixed Reality Link, which can be configured to their needs. For example, somebody standing next to them in physical space might not even be aware that they are interacting with a virtual 3D environment. This is reinforced by the fact that it is them who have control over the link itself. They control who they make it available to and who not. Finally, within Second Life, inhabitants can take on different virtual representations or avatars that they can customise to a certain extent. It is this representation that other inhabitants see and interact with.

**Co-presence:** Co-presence between inhabitants is then simulated within the virtual spatial framework of the online environments. Movements and changes in orientation are conveyed as those of the associated avatars. These are visible and legible by others who have the same set of abilities. However, as the mobile Mixed Reality Link itself is private (owned by a specific inhabitant), co-presence

is only provided between people who have control over the interface, i.e. those who are holding it. This is very different from architectural interfaces that are fixed and public, where anyone close by has the same access to the linked space.

**Limits to the experience:** In this example, the limits to our experience in the virtual space are mainly determined by properties of the Mixed Reality Link, as has been discussed above regarding the access to space and across the link. In addition, the Second Life interface limits the experience further. For example, inhabitants cannot be virtually harmed.

**Targets of links:** The targets of links are determined by the spaces that are linked. During its lifetime, i.e. during the time the mobile phone is on and the Second Life interface is running, links are public in principle. Anyone looking at the mobile phone screen with the owner, will link into the same virtual space as they do. In general, this link is not segmented but it could easily be, for example when two inhabitants with a mobile phone each link to the same virtual space in Second Life, looking at it from different orientations.

**Topology:** Finally, the spatial relationship between the physical spaces linked from and the virtual spaces linked to, remain unmapped, i.e. the position of the inhabitant in either space, does not affect their position in the respective other space.

The above has demonstrated the application of the framework of Mixed Reality Architecture to a general Mixed Reality system, the 3D virtual environment Second Life accessed from a mobile handheld device. This example illustrated a system designed in a particular way, which makes it mainly individual in nature, as it is being accessed from an individual handheld device. Other designs that are much more publicly legible are clearly possible and are the focus of the development work in this research.

Overall, the framework underlines the potential of MRA to introduce a degree of spatiality to telecommunication between physical sites and also introduce a degree of flexibility to physical architecture. What remains unclear from this theoretical overview however is the relationship between a society or community inhabiting such architecture and its topology. It has been argued at the outset of this thesis that physical architecture structures patterns of co-presence and that architecture in turn is structured by the rules and norms of the society that inhab-

its it. What the nature of this relationship is within MRA must be a key area for further research and must be added to the original research questions concerning the topological flexibility of architecture and the application of architectural theory to telecommunications technology.

To investigate this further, it seemed only appropriate to build MRA and explore its use in detail. At present, Mixed Reality systems tend to be set up as lab experiments or for very specific occasions outside the lab. These are often of a short-term nature. In contrast, architecture is usually occupied long-term and Mixed Reality Architecture, if its inhabited state is to be investigated, also needs to exist for the medium to long term and ideally be part of the everyday activity of a setting. What is proposed here are the design, development and evaluation of MRA that has the specific aim of reintroducing a level of spatiality into communication across physical and virtual environments supporting everyday social interaction but potentially also more specific collaboration tasks that require a spatial context, such as design, rehearsal or some forms of gaming. It is clear that very real constraints given by the particular interface technologies chosen will have to be faced and this will result in the actual MRA being different in a number of ways from the idealised framework that was presented above.

# 4

## Methodology

Further developing the areas that were identified above required the design, construction and evaluation of Mixed Reality Architecture in an everyday setting. Although it was possible to base certain design decisions on precedence and on the experience with related technologies and set-ups, it was also clear that many issues would only come to light when MRA was actually inhabited. These issues might be a result of reflections on the design by the architect but also of the concerns and expectations of inhabitants themselves. To capture these it was decided to adopt an iterative design and prototyping process as the main method of enquiry for this research.

Two major prototypes of MRA were developed within an everyday office environment. In addition, the second prototype was also iteratively refined through a series of smaller prototyping steps. This process needed to reflect currently available technologies and the work practices at the given settings. As MRA was still a novel architectural concept, issues were still emerging and design criteria were



being shaped. The different stages of this process were refined by collecting data using a variety of mainly qualitative measures and feeding the analysis of this data back into the ongoing and situated design process. This chapter provides an overview of the prototyping process of MRA before introducing the tools for its evaluation.

#### ***4.1 Prototyping Mixed Reality Architecture***

Within the field of architecture, prototyping is a well established practice in the form of model making, which is employed widely during the architectural design process (Mills, 2000). Models can be physical and are then usually scaled, increasing in detail and refinement as the design process goes on. They can also be virtual and are then usually provided within a desktop application, which allows viewing but not usually interaction. Sometimes a sense of immersion can be added by allowing viewers to use head-mounted displays or projection environments (Campbell and Wells, 1994). What these types of models cannot provide is the 'lived-in' quality of a real building particularly when longer time scales are of interest.

There are also other developments that go beyond model making. Lab spaces have been set up to explore the experimental construction of pieces of architecture, as for instance at the University of Manitoba, Canada (Alter, 2003). Prototype houses have been constructed to explore different aspects of technology. The Eco House at Nottingham University was constructed to be able to experiment with the latest energy efficient technologies available in construction (School of the Built Environment, 2003), while researchers in computer science explore the integration of computing technology into living laboratories (Intille, 2002, Kidd, et al, 1999). The focus of these projects has been very much technological and on creating new 'show' homes that serve their specific purposes. In a way in response to the above projects and inspired by Brand (Brand, 1994), Rodden et al emphasise the need to consider the changing nature of people's homes when situating technology. The shape of buildings is influenced by inhabitants themselves but also by outside powers and these changes occur over varying time scales. While technology changes very rapidly, buildings change more slowly (Rodden and Benford, 2003).

The above also points to one of the problems with a prototyping approach within architecture. Through its mere size and complexity, conventional architecture is not really suitable for rapid adaptations. It is simply not that easy to replace parts of a building for experimentation, although there have been attempts to overcome this, for example Cedric Price's Generator project and Interaction Centre (Price, 2003) as has been mentioned previously.

Within other design disciplines, prototyping is used much more widely. Automotive and product designers routinely work on mock-ups, often full sized ones, to evaluate design choices. These models can be physical but are increasingly virtual (Buxton, et al, 2000). Prototyping approaches are also being used in computer interface design. Gould & Lewis propose an iterative design process involving end users for systems design (Gould and Lewis, 1983). An overview of low-fidelity prototyping of interfaces is provided by Rettig (Rettig, 1994). The author contrasts formative evaluation and summative evaluation. The former tests for iterative changes to a design and feeds back early results into the prototyping process, while the latter attempts to evaluate the finished product. Prototyping has also been suggested for the development of interactive physical products, allowing designers to attach user input devices to rough physical prototypes adding interactivity through the widely used Macromedia Director™ software (Avrahami and Hudson, 2002). In addition, physical prototypes have been augmented with projections of virtual material and additional detail (Verlinden, et al, 2003). Finally, the iterative design process of the Augurscope, a mixed reality interface for outdoors has given the author experience with prototyping technology (Schnädelbach, et al, 2004).

For the research concerning Mixed Reality Architecture, prototyping appeared to be an ideal approach made easier by the fact that changes could be made within physical as well as virtual space. The aim was to design, build and then evaluate experimental pieces of architecture and then to study a workable solution for an extended period of time. Rather than create an artificial, experimental setting, the prototype was implemented in the middle of working and very active research environments: mainly the Mixed Reality Laboratory (MRL) at the University of Nottingham but later also at the Psychology department at Bath University, the Centre for Virtual Environments (VR Centre) at University College London and the Virtual Environments and Computer Graphics (VECG) group at University

College London. Putting this into practice brought up a number of issues that need to be reflected on: the situatedness of the prototype, the pool of participants available in these particular settings and the technology or building materials available for construction. As the main site for constructing the different prototypes of MRA was the MRL in Nottingham, it will serve as an example here. As all the other sites are also higher education institutions, the situation there is very similar.

#### **4.1.1 Situatedness**

Constructing MRA meant two things. On the one hand this introduced a novel piece of technology into people's environments. On the other hand it introduced changes to the architecture and social interaction possible within the architecture that people inhabit. Both the above required some understanding of the organisation MRA was being placed within. Issues like the spatial layout and the activities of the organisation needed to be taken into account.

##### ***4.1.1.a Spatial distribution***

The MRL carries out research into various aspects of the merging of physical and virtual environments and these touch upon a number of different disciplines. As a result, the team of researchers is very much multidisciplinary, with the departments of Manufacturing Engineering, Psychology and Computer Science contributing resources when the MRL was set up at the end of 1999. These departments are spatially separate, with the former two being located on the main university campus and Computer Science being located at the new Jubilee Campus. Generally, interaction between researchers takes place via email, telephone and in physical meetings. The latter need to be arranged when researchers from the two separate campuses are concerned. Chance encounters of people located on different sites are relatively rare. During the first year of the MRL's existence, weekly seminars were held on Jubilee Campus bringing a number of MRL researchers together on a regular basis. However, this series was stopped, because it was felt that the travel involved became too much of a burden, considering that each of the groups would have their own seminar meetings respectively at other times. In addition to the above, the MRL participates in a number of collaborative projects that involve partners from other sites across the UK and also interna-

tionally. The VECG and the VRCentre, both at UCL, have been project partners for a while and the Psychology department at Bath has become a partner with the recent move there of a lecturer from Nottingham. Researchers communicate via the same media already mentioned but a considerable amount of physical travel is also required. This situation is representative of many of today's organisations that are spatially distributed but do have groups of people who need to work together on a regular basis.

#### ***4.1.1.b Organisational changes - spatial changes***

The core of the MRL is the main lab space on the first floor of the north wing of the Computer Science building on Jubilee Campus. This is where the bulk of the research work takes place. There are a number of offices associated with this space. At the time of studying the first prototype, 'Presenting in Mixed Reality' (see chapter 5), senior staff were located at one end of the main lab while junior staff and PhD students were located on the second floor of the southern wing of the Computer Science building. By the end of the year 2000, junior staff and PhD students moved to the north wing, which also brought an increase in the available office space. In the following years, the main lab space was expanded and from then on included a separate meeting room and space for administration. In 2004, the Learning Sciences Research Institute (LSRI) was established on the ground floor in the north wing of the building. The LSRI is functionally attached to the MRL (with joint projects and jointly supervised PhD students for example) and there is some staff overlap. This was the situation during the study of the second prototype, 'Mixed Reality Architecture' (see chapters 7 - 8 ), conducted between October 2003 and October 2004.

In just over 4 years, substantial organisational changes have taken place that resulted in changes of the spatial layout of the lab. This fairly frequent need for spatial change is another aspect typical of modern organisations. While it is relatively straight forward to move people, changing the spatial layout is much harder. The building work required for the change mentioned above did cause a considerable upheaval.

### 4.1.2 Participants

Participants in the two studies were drawn from a pool of researchers already working within the actual settings. They were therefore all linked to research within higher education. Most had a background in Computer Science, while there were also people with backgrounds in Architecture and Psychology. All participants were volunteers and were not remunerated for participation. Full details about the participants are included in chapters 5 and 7 – 8 covering the two major prototyping stages.

## 4.2 *Evaluating MRA*

The considerations above resulted in two distinct MRA prototypes: firstly a focussed short-term study and secondly a longer-term exploration. They were chosen to address specific aspects of the framework but also answer to requirements of the actual setting that these studies were conducted in, as will be shown below.

The short-term study looked at some of the design choices and emerging properties of MRA. The study was more exploratory, attempting not only to chart a certain area of the design space but also to identify some key issues that could be taken forward into the second part of the implementation. The aim was also to identify opportunities for re-design in areas that had not been considered previously. Details of this study can be found in chapter 5.

The long-term study involved a number of prototyping iterations in itself and was built on initial findings from the pilot. Rather than being staged for a specific trial it was located in an everyday office setting. The iterations had the aim of evaluating the basic functionality of MRA, creating a workable prototype and evaluating this final prototype long term. Gradually, as prototypes became more refined, the research was able to focus more on the architecture of MRA rather than the technical functionality. This focus was on the dynamic topology of MRA and its effect on patterns of co-presence of people who are remote from each other. Details of this second part of the prototyping process can be found in chapter 6 – 8.

It must be made clear that the research presented in this thesis is of course framed in a specific way, and that, within a prototyping process, only what has

actually been built can be evaluated. Specific design choices had to be made at the outset of the design process and this naturally precluded certain things. There would have been alternative design options that were not implemented and not investigated during this research. In addition to this, MRA was implemented with a specific set of technologies and a specific setting. As mentioned previously the framework of MRA is an attempt to chart the design space without being influenced by available technologies, but of course this is impossible for the actual construction of MRA.

#### 4.2.1 Methodological considerations

For the discussion of a suitable evaluation methodology, it is worth taking a step back to look at the relationship between prototyping and evaluation. Evaluation in support of an iterative prototyping process must be seen as an ongoing activity that continues throughout the development process. During the early stages, evaluation informs the following step in the development, while during the final stage the overall design can be evaluated in light of the previous findings and the overall design decisions. The prototyping process itself can be broken down into four specific phases. During *Functional Selection* the functionality of the prototype and the activities it should support can be defined. During *Construction*, prototypes are built and made available for testing. These prototypes do not have to be complete but might instead focus on a particular issue to investigate. However, the prototype should be complete enough to enable end-users during the *Evaluation* to feed back information about the usability of the prototype. Finally, during *Iteration* the results of this feedback can be channelled back to further stages in the development (Floyd, 1984) (Crabtree, 2003).

The nature of this process raises a number of issues regarding its cyclical evaluation. Traditional experimental approaches so frequently employed within the field of Human Computer Interaction (HCI) are difficult, if not impossible to apply in a prototyping process as many measures cannot be pinned down with an unfinished system. Issues to investigate are still emerging and one of the main aims of prototyping is to uncover exactly these issues. There is also the more specific problem (as indeed with other novel computer systems in general) of the situatedness of the prototype as already mentioned. The evaluation of MRA did not take place in a vacuum but instead had to reflect on the work practices and

already existing social interaction within the places where it was constructed. The emphasis of the evaluation must move away from mere system functionality to system use in the setting it was designed for. Twidale et al propose an 'informal' approach to evaluating prototypes in these circumstances (Twidale, et al, 1994). By using this term the authors contrast this approach to summative, quantitative evaluation conducted through controlled experiments at the very end of development. Their formative, qualitative and opportunistic approach making use of ethnographic observations is designed to evaluate prototypes early on and before the exact requirement or the terms of the evaluation have been set. This again points to the fact that this process has to be adaptive to the needs of any of the development phases, and allows researchers to evaluate development stages quickly and cheaply.

For the evaluation of MRA, a variety of methods was employed to assist, on the one hand the ongoing design process, but on the other hand, to assemble a detailed picture of what it means to inhabit the environment. Those methods were chosen on the basis of their suitability for making the phenomenon of inhabiting MRA observable and on the basis of their 'availability' within the particular circumstances in which MRA was being developed. The following sections will consider these methods in turn including previous applications in related areas, their implications and also their limitations.

#### **4.2.2 Situated observational study**

Naturalistic, observational studies have already got a long track record in the design of interactive cooperative computer systems, emphasising the situated nature of work activities and the systems developed for those settings. Naturalistic methods have proven successful in studies of the workplace and in computer supported co-operative work (CSCW) in particular. Heath et al provide an overview of some of this work, its methodological concerns rooted in ethnography and its implications for our 'understanding of work, technology and organizational conduct' (Heath, et al, 2000, p.300). Although there are a variety of analytical approaches, the authors argue that those are connected by their overarching concern for the analysis of technology with ethnographic means.

Ethnography, as used in these studies, is a particular type of field work attempting to record social life as it is taking place. One of the main characteristics of

ethnography is that of taking a 'first hand look at the phenomena that one is purporting to talk about' (Sharrock and Hughes, 2000). Ethnography carries with it a 'commitment to a period and degree of immersion in the social setting being studied that is sufficient to reach a qualitative understanding of what happens here' (Shapiro, 1994). Instead of starting with a theoretically pre-structured world-view, ethnography sets out to record life as it presents itself to the observer. Indeed, as Crabtree points out, at the beginning of a study it is not possible to set out what one might be looking for (Crabtree, 2003).

The collection of material for such an inquiry is very broad during the initial exploration phase, taking in any material that can faithfully represent the setting to be investigated. This could be among other things, co-located or remote observations, group discussions or records produced at the setting, for example. During inspection, emerging categories of interaction can be identified and might be used to target further data collection.

In terms of criticism of this method, it is often argued that generalisations from qualitative sets of data and specifically ethnographic data have to be done with care, because they can be very specific to a particular situation and can be tied to the experience of the ethnographer who collated the data. This is part of a wider discussion and Sharrock et al propose looking more closely at how the outcomes of ethnographic studies can be accumulated over time as a way to make the results of individual ethnographies more widely relevant (Sharrock and Hughes, 2000).

Typically, ethnographic tools have been employed to study existing, situated social practice. In contrast, in the case of MRA there is no practice yet to study since experiences with MRA are necessarily staged at least in some respect. However, ethnographic methods have already been employed in a number of other design contexts, often connected to the development of CVEs. What follows are a few examples.

Benford et al describe their use of ethnography, in combination with the analysis of data logs, to evaluate the public staging of CVE experiences (Benford, et al, 2002). Ethnographic methods allowed the authors to focus on the social circumstances that their work was being deployed in, feeding back information to designers about how interaction between participants was coordinated and how



socially demanding a new technology might be in use. Crabtree follows a similar approach when he suggests treating the deployment of novel technologies as *breaching experiments*, an approach originally developed by Garfinkel and designed to make visible everyday social action that is usually taken for granted. One example that the author presents is that of Garfinkel giving his students the task of bargaining in shops that usually have set prices and report back on their experiences. Crabtree argues that this approach makes observable 'the contingent ways in which the technology is made to work and the interactional practices providing for and organizing that work' (Crabtree, 2004).

Information gathered through this process might then be used to further the development. Indeed, Bowers et al in their ethnographic analysis of a CVE in use make suggestions of what might be developed as a result (Bowers, et al, 1996). Their overall argument concerns the importance of considering the work needed to accomplish interaction within a CVE and more specifically how important the physical deployment context becomes. Rather than concentrating on technical aspects and aspects internal to the CVE itself, the authors make clear the need to develop for both worlds, physical and virtual.

The information gathered with ethnographic tools can be approached in a number of different ways and those approaches follow a variety of theoretical orientations. Sharrock et al provide a succinct overview of the theoretical agendas attached to the most common approaches to ethnographic data as used in system design (Sharrock and Hughes, 2000). The main concern in these discussions is the role of theory and whether it is applied to field data, field data is used to develop theory, or in case of the ethnomethodological approach, whether theoretical abstractions are the right instrument for describing society at all. The details of this discussion go beyond what can be covered in this thesis, and indeed Sharrock et al point out that the designer need not worry about these unduly (Sharrock and Hughes, 2000).

The main concern for the research conducted here was to provide a way for making use of the gathered data during the development phase and also the evaluation of the final prototype. Some observations, certainly earlier on in the development phase, were used to make rapid changes to MRA to test out different options. For the longer term study, approaching the field data collected for this research, involved building up a detailed description of what is involved in

inhabiting Mixed Reality Architecture. These descriptions or *vignettes* can include transcriptions of verbal interactions as well as accounts of non-verbal interactions, illustrated by video stills and map snapshots. At another level these can include abstractions in terms of what inhabitants were actually attempting to achieve.

Details of the use of the material gathered from the observations work can be found in section 5.2 for the pilot study and section 8.1 for the long-term study, respectively.

### 4.2.3 Interviews

Interviews are one of the most widely used methods in social science research, probably because asking a question is our most instinctive method for gathering information, as Fielding et al indicate (Fielding and Thomas, 2001). Interviews can be split into three broad types: standardised, semi-standardised and non-standardised. Standardised interviews, often also called structured interviews, are conducted with the use of a rigid schedule, containing all the questions to be asked. The questions and the order they are asked in is strictly preserved from one interview to another. In contrast, semi-standardised or semi-structured interviews are more adaptive. Researchers use an interview guide to ensure that certain questions are covered, but may also add questions or request more detail on answers given previously. This can also account for the fact that answers to one question sometimes also provide answers to other questions to be asked later in an interview. Finally, non-standardised or unstructured interviews are concerned with discussing a list of topics with interviewees. The order in which issues are discussed is adapted to the situation and the interviewer might include what they think of a specific topic themselves. For all three of the types, the responses can be recorded directly on to the schedule in written form or recorded on tape, and then have to be transcribed at a later stage.

As Simmons points out, there are at least two main advantages of interviews: they are more flexible than standardised surveys and there is an interviewer present who can be approached for more information if required (Simmons, 2001). Interviews also tend to extract more information than self-administered surveys for example. However, they tend to be costly, simply as a result of the fact that an interviewer has to administer each one of them, and they are also time-

consuming when it comes to analysing the data collected. There also concerns about the influence of the interviewer and the influence of the actual questions being asked on the responses by participants. Overall, the main strengths of unstructured or semi-structured interviewing lie in eliciting information in the early stages of an evaluation or pilot study, when issues of interest are still emerging.

The uses to which the data gathered can be put are varied as Fielding et al point out (Fielding and Thomas, 2001) and interviews already have a long track record in HCI research. Olson conducted such interviews over the phone to gather information about the then emerging trend towards tele-working (Olson, 1983). Wood made use of semi-structured interviews in the early phase of application development with the aim of developing a model of people's work and the tasks involved in that work (Wood, 1997); while Haynes et al built up use scenarios in the evaluation of collaborative systems from data gathered from this method (Haynes, et al, 2004).

The analysis of semi-structured interviews is concerned with identifying themes and concepts by considering the data collected (Fielding and Thomas, 2001). These concepts are then coded according to a scheme that was either developed beforehand or is directly derived from the data. If new issues arise later in the analysis, the coding scheme needs to be adapted and previous analyses re-examined. In contrast, the analysis of structured interviews more easily allows the application of statistical methods, as responses should be easier to code or can actually be pre-coded, when closed questions are being used (Simmons, 2001).

Semi-structured interviews were used for the initial pilot study in this research and details of their application can be found in chapter 5. A structured interview survey was employed to get an impression of the existing social networks of prospective inhabitants of the yet-to-be-built MRA. Details of this can be found in chapter 7.

#### **4.2.4 Sketch maps**

Asking participants to draw a sketch map of the environment under investigation in a particular study is a very useful method to gather information about people's internal spatial representation or cognitive map of that same environ-

ment. A cognitive map is defined by Kitchin et al as a 'term which refers to an individual's knowledge of spatial and environmental relations and the cognitive processes associated with the encoding and retrieval of the information from which it is composed' (Kitchin and Blades, 2002). In a sense, the term 'map' is therefore slightly misleading, as it is not proposed here that people maintain a cartographic representation.

Internal spatial representations can be investigated using a range of techniques (Gärling, et al, 1997). The use of sketch maps is one of the main methods and this task is usually conducted very simply with a sheet of paper and a pen. However, this can take different forms as the task can be completely free, it can include instructions of what the map should take account of and can also be conducted with the support of cues provided as starting points. Researchers have also studied the drawing process and have experimented with providing a common language for the drawing of maps. Sketch maps have the advantage that they are easy to administer and that many people are already familiar with drawing maps, usually to give directions to others (Kitchin and Blades, 2002). The direct end-product of a sketch map task is a spatial representation depicting environmental features and their relationships (Newcombe, 1985). However, their use is confounded by an individual's graphical skill; certain groups have fundamental difficulties expressing themselves in this way, which would apply to children and the visually impaired, for example (Kitchin and Blades, 2002), and by the need to translate between internal and external spatial representations. Of course, an important factor in this context is whether sketch maps are actually a reliable measure. Blades, by studying multiple sketch maps drawn of the same environment by the same individual over time, makes a strong case for their validity (Blades, 1990).

Sketch maps have been used in a variety of contexts. Lynch established this method in his seminal *Image of the City* (Lynch, 1960). In the late 50's, Lynch and his colleagues attempted to understand the perception that citizens had of their cities, concentrating on visual and spatial characteristics of those cities. Since then sketch maps have been used in a wide variety of studies of the physical world, such as an investigation into the spatial knowledge that tourists gather of large-scale natural environments (Young, 1999), an investigation into the representations that people have of the entire world as influenced by certain characteristics

of individual countries (Pineiro, 1998) and an attempt to understand students' perception and understanding of their campus library (Horan, 1999), among many others. The method has also been employed in the study of virtual spaces. Sketch maps have been employed to investigate way-finding behaviours in virtual environments (Darken and Sibert, 1996) but also to better understand the difficulties in learning through 3D representations of data sets (Johns, 2003). Billinghurst et al report on the validity of using sketch maps for measuring how people understand the topologies of virtual environments, suggesting that this method appears to be better suited for relatively dense, rather than sparse or featureless environments (Billinghurst and Weghorst, 1995).

What was of interest in the context of this research was whether inhabitants of MRA build up an internal representation of the overall topology of MRA and what this representation might look like. Sketch maps were a particularly interesting method in this context as currently there does not appear to be any reported research using this method to investigate people's internal representations of Mixed Reality environments. Sketch maps were employed for the pilot study and their concrete application is further described in section 5.2.

#### **4.2.5 Replaying virtual environments**

System activity logs are a widely used tool within Computer Science that allows researchers to understand certain technical aspects and constraints of a particular technology by inspecting recorded performance data. The throughput of processors, the performance of networks or indeed the behaviour of a virtual environment can be logged and later analysed, often using statistical means, to understand the behaviour of a system under load. Greenhalgh used system logs to analyse MASSIVE, a software platform for Collaborative Virtual Environments (CVEs). By analysing movement patterns of participants in six different staged meetings, he was able to draw conclusions on a number of technical aspects, such as required bandwidth for movements or necessary pre-fetching of parts of an environment (Greenhalgh, 1997). Replaying such data for later analysis is a different matter and Hart argues strongly for the need of being able to replay virtual reality to make it useful for scientific enquiry (Hart, 1993). Reflecting the available technology at the time, the author suggests concentrating on the development of image-based rather than object-based recording of VR. While the

former can only represent a small portion of a VR, it is robust and simple. The author argues that object-based recording, while providing free navigation within the recorded data, might be difficult to replay considering frequent changes in operating systems and computing hardware. However, object-based recording has been developed subsequently as a result of new technologies being available and has proven very valuable in a number of circumstances. Imai et al discuss three applications of replaying virtual environments: a virtual mail system, an annotation system for VR, and a VR recorder that allows the replay of entire environments (Imai, et al, 2000). Based on their earlier work on logging system use, Greenhalgh et al introduced and demonstrated their concept called Temporal Links, which allows the placement of recorded virtual environments into live virtual environments and the adjustment of the temporal, spatial and presentational relationship between the two (Greenhalgh, et al, 2000). This type of technology has then been used to support the evaluation of CVEs in a number of different contexts (Benford, et al, 2002). In particular, the ethnographic analysis of the staged CVE event Avatar Farm has been supported by replaying the event and being able to reveal additional information and to adapt the view point within the environment. More recently, a tightly coupled analysis of ethnographic material and system logs has allowed Benford et al to reveal the reasons for observed difficulties that participants had with a Mixed Reality Experience (Benford, et al, 2005). For the analysis of the main study of MRA, the MASSIVE3 Record & Replay technology which is based on Temporal Links was used. Details of its application can be found in section 8.1. In addition, the log data has also been subjected to statistical analysis and details can be found in section 8.2.

### ***4.3 Multi-method evaluation***

This chapter has outlined the methodological orientation of this thesis. The choice of an iterative design and prototyping approach using early and continuous evaluation has been motivated by a number of key qualities of the proposed research: the novelty of the concept, the lack of practice around that concept, the distributedness of the prototype and the situatedness of the prototype. The use of situated observational studies, interviews, sketch maps and the replay of virtual environments have been introduced in general and their limitations discussed. It is felt that this combination of methods supported the design choices at different

stages and provided very well for a detailed analysis of the final prototype. The specifics of each method and its application within the design process will be introduced in the following four chapters where appropriate.

# 5

## Study 1: Presenting in Mixed Reality

The design, implementation and evaluation of the initial pilot study in the prototyping cycle of Mixed Reality Architecture will be outlined in this chapter. The study 'Presenting in Mixed Reality' was conducted at the Mixed Reality Laboratory (MRL) at the University of Nottingham in May 2000. It was designed and implemented in co-operation with Dr. Borianna Koleva, then a PhD student. The main aspects of this study have been published in GROUP 2001 (Koleva, et al, 2001).

As already mentioned in the previous chapter, the MRL is distributed over a number of physical spaces and its configuration is subject to relatively frequent changes. Also, it has already been outlined how regular meetings and the weekly seminar series originally held in the MRL meeting space have been negatively af-



fectured by these changes. For this study, a prototype Mixed Reality Architecture was set up that provided an environment for distributed presentations given by local and remote speakers to local and remote audiences. This MRA linked four physical spaces across one virtual space. The study took the form of a staged event and focussed on a number of key issues with the aim of starting to evaluate the concept of MRA especially in terms of its dynamic properties and its influence on co-presence between people not physically co-located.

It was also concerned with gaining a better understanding of giving presentations to distributed audiences, where speakers and audiences communicate over a computer network instead of physically travelling to meet face-to-face. Although it might be said that the need to reduce travel has become more pressing in recent times due to the cost to the environment, and although some audio-video conferencing and text chat systems have enjoyed commercial success, it has proved difficult to replace face-to-face presentations with virtual ones. The research introduced in section 2.3.1.a has shown that there were a number of recurring issues that have emerged. In addition to the summary provided in the above section it is also worth briefly reflecting to the particular issues that have emerged from previous attempts to support remote presentations.

Frequently, speakers reported that it was difficult to understand the local situation of the audience and that they were often unable to gauge audience reaction (Isaacs, et al, 1995, Jancke, et al, 2000). Similarly, audience members were often unaware of each other and could not gauge each other's reaction to the material presented (Isaacs, et al, 1995). All parties experienced difficulties with many of the subtle but important aspects of everyday face-to-face communication such as turn taking and gaze direction (Mark, et al, 1999). Researchers have argued that these problems arise at least in part because the participants do not share a common integrated space (Heath, et al, 1995) (Ishii, et al, 1992). In response to these observations, new distributed presentation technologies have been developed that attempt to establish an integrated space for virtual meetings. These include those that introduce physical and those that introduce virtual spatial frameworks, as detailed in sections 2.3.1.a and 2.3.1.b respectively. Here, a different approach has been taken, in effect combining a physical spatial framework for local participants and a virtual spatial framework for remote participants. The

following sections outline the design, implementation and evaluation of this pilot MRA.

## ***5.1 Design and implementation***

It appeared that Mixed Reality Architecture offered a number of properties that would be useful for supporting distributed presentations. With the use of MRLinks, physical and virtual spaces could be joined to provide a common mixed reality interaction space, in which distributed presentations would take place. The aim in this context would be to establish a sense of co-presence between people physically not co-located. Establishing a topologically dynamic MRA would allow the response to the different requirements that speakers and audiences might have in different circumstances.

As part of the overall development strategy, the pilot study was designed to start investigating the issues involved in creating MRA with a view to take results forward into the next development cycle. At the same time, the study also had to look at the particular application domain, distributed presentations, and the suitability of MRA in that area. In the following, the pilot study will be described in terms of the events taking place, its architecture and its technical set-up.

### **5.1.1 Events**

The study involved two sequential distributed presentations. For the first half of the study, a remote speaker presented a talk to both remote and local audiences. During the second half, a local speaker (co-located with the local audience) presented to remote and local audiences. The local audience and speaker attended from a space that was set up within the MRL main lab space, while the remote audience and speaker attended across a connected virtual space (for details see the following section).

The presentations lasted for 10-15 minutes and were supported by slides displayed on screens available in the respective spaces. Both presentations were followed by a question and answer session that lasted for 5-10 minutes. Between the two presentations, changes to the architecture on both sides were made to allow the speakers to take their new positions. There was a period of introduction and preparation before the start of the first presentation, lasting about 10 min-

utes. The total time for the entire experience was just under an hour. A detailed schedule of events can be found in Appendix 11.1.1.

### 5.1.2 Design

The presentations as described above took place in a small prototype MRA. One local physical presentation space and three remote physical office spaces were connected to a virtual presentation space. One local speaker and four local participants were located in the physical presentation space, which was set up in the Mixed Reality Lab. They had direct access to the physical side of a Mixed Reality Boundary (see section 2.3.1.c as well as Figure 8). One remote speaker and four remote participants were located in separate physical spaces on a different floor of the same building. They had indirect access to the virtual side of the Mixed Reality Boundary (see Figure 9) by entering the virtual presentation space with a head mounted display (remote speaker) or desktop computers (remote audience) respectively.

For the design of the MRA four distinct perspectives were carefully considered; the different perspectives of the local and remote speakers, the perspective of the local audience and the perspective of the remote audience. Clearly a number of design choices were made when setting up this environment and these are considered in turn below, before considering the actual Mixed Reality Architecture designed and implemented.

#### **Support for spatial orientation**

A number of elements were included in the design to help people navigate in virtual as well as physical space and find a position suitable for following the presentations. In virtual space, elements similar to physical public spaces like handrails and markers for positions were used. However people were not restrained in any way in their freedom of movement. Also, the fields of view (FOV) of virtual and physical cameras were marked out in both spaces to give participants a notion of when they could be seen and when not. This was designed to encourage them to stay in positions that would allow the spaces to be perceived as integrated. Finally, lighting in virtual and physical space and texturing in virtual space were used to emphasise focus areas, and curtains in physical space bounded the area of the experiment to cut it off from its surrounding physical space.

### **Participant representation**

Effectively, there were three different types of participant representation. Firstly, the local audience members and the local speaker were represented as themselves. They were visible to the remote participants through the live video taken from within the physical presentation space. Secondly, the remote audience members were represented with very simple avatars (see Figure 9 and Figure 12). These had a different colour for each of the participants, but were otherwise identical. Using mouse and keyboard they were able to move around and rotate on the ground plane of the environment. Finally, the remote speaker was represented in a very similar way. However through the use of a tracked Head Mounted Display and hand trackers, the remote speaker was able to move his virtual head and point within the virtual space. The intention was to provide him with a more expressive avatar that could gesture, point and use some measure of gaze direction (at least head orientation) to interact with audience members. Using a handheld mouse he was also able to move around and change orientation on the ground plane of the environment.

### **Spatial integration – co-presence**

The design was aimed at making the two presentation spaces appear integrated as one Mixed Reality space to strengthen the sense of co-presence between participants. Therefore all participants were made visible to each other at all times. The topology that makes this possible is a triangle with the three nodes being the local audience, the remote audience and the speaker (local or remote) respectively. The positions of the speakers were slightly favoured, as their awareness of the audience was considered more important than the mutual awareness between the two audiences. This was designed to make virtual and physical audiences appear as one and to allow speakers to address both audiences at the same time. However, it also allowed the two halves of the audience to be aware of each other, this being crucial for question and answer sessions. Other measures for integration were spatial consistency with the same co-ordinate system on both sides, and temporal consistency. Interaction across the MRA was synchronous, within the restrictions of the technology used.

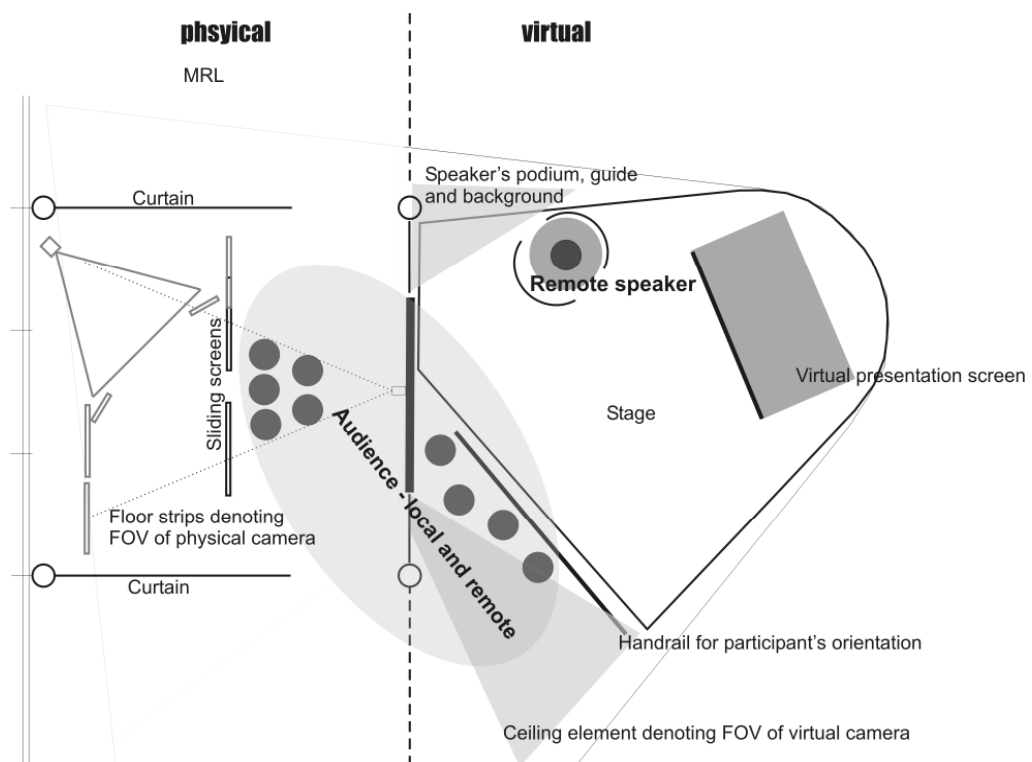
### **Dynamics**

One final aspect of interest was that between the two presentations the architecture was changed on both sides of the MRB. This was to adapt the spaces to the

two distinct events and again help participants navigate to suitable positions. This change can be seen by comparing Figure 7 with Figure 10 below. The changeover took no longer than five minutes, suggesting that an MRA can be reasonably quickly adapted to different presentation situations. Within virtual space, parts of the geometry had been configured so it could change position on a set trigger. Within physical space the changes were done manually, while the automation of this process is clearly conceivable and is of course already being done, in theatres for instance. The virtual parts of the resulting design proposals were then prototyped and tested within the modelling package used to generate 3D content but also within the actual platform that was going to be used to run the pilot study. What follows is an outline of the resulting overall MRA, with the two distinct configurations that are a response to the requirements of the two types of speakers, local and remote.

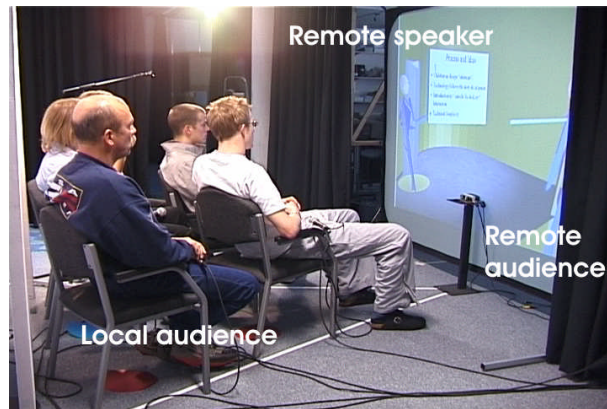
#### 5.1.2.a *MRA for Remote presentation*

During the remote presentation the physical audience (on the left of the diagram shown below) was seated and faced the mixed reality boundary so that its members were looking directly into the collaborative virtual environment. Each member was given a hand-held microphone.



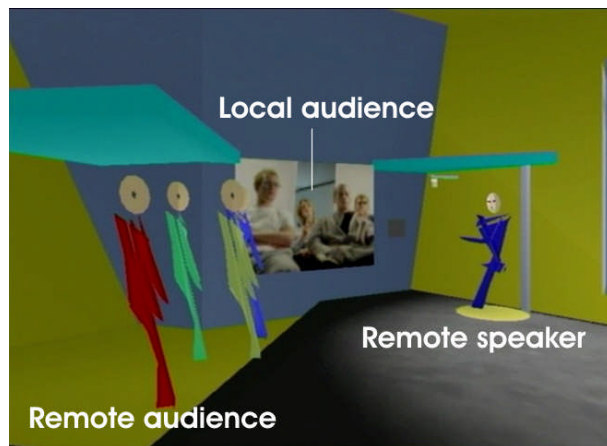
**Figure 7 MRA for the remote presentation**

The physical audience saw the virtual speaker and the virtual audience in the virtual presentation space as projected onto a screen in front of them (the physical side of the mixed reality boundary – see Figure 8).



**Figure 8 Remote presentation: view from physical space**

The virtual presentation space included a virtual screen for showing slides as texture-maps and guide rails and floor markings to help the virtual speaker and audience position themselves (see Figure 9).



**Figure 9 Remote presentation: view from virtual space**

An essential part of the mixed reality boundary was that the virtual space also contained a live video window looking back out at the physical audience. As already mentioned above, the virtual speaker (and their virtual screen), virtual audience and physical audience were carefully positioned to establish an approximately triangular relationship between them, allowing each class of participant to see and hear the others. The narrow shape of this triangle was designed to slightly favour the relationships between the audiences and speakers over the relationships between the two audiences.

### 5.1.2.b MRA for Local Presentation

For the presentation by the local speaker the layout was changed substantially to offer the same properties to participants as the previous configuration. This change became necessary because of the changed speaker position. Figure 10 shows the layout during the local presentation with the same virtual and physical spaces still linked.

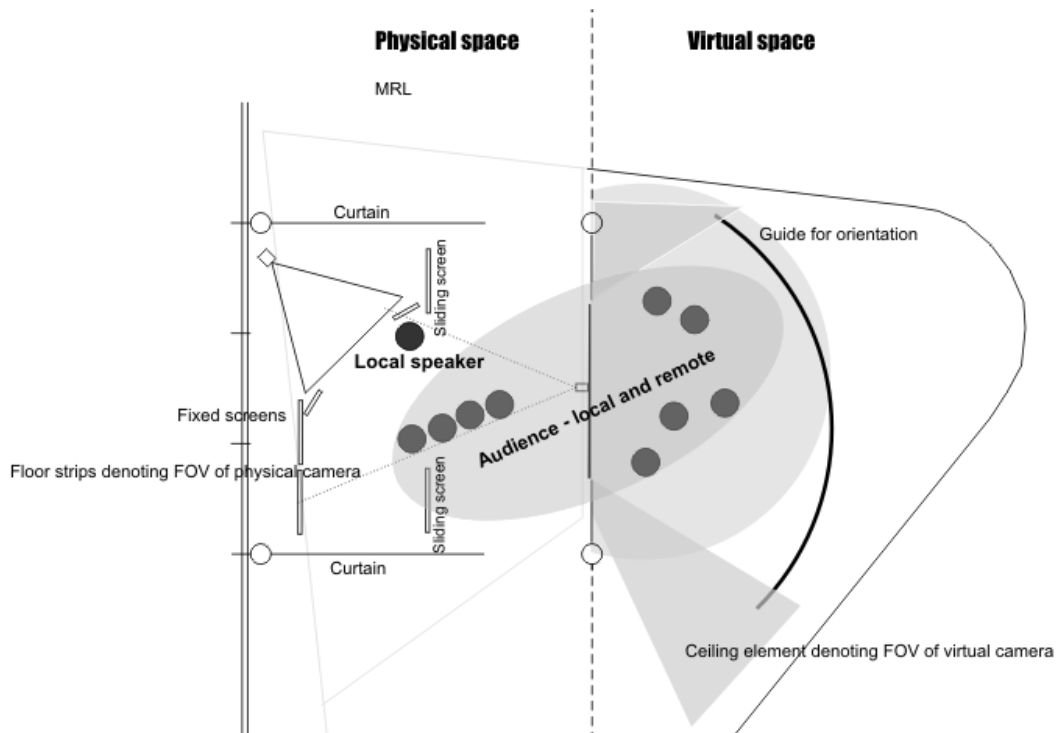


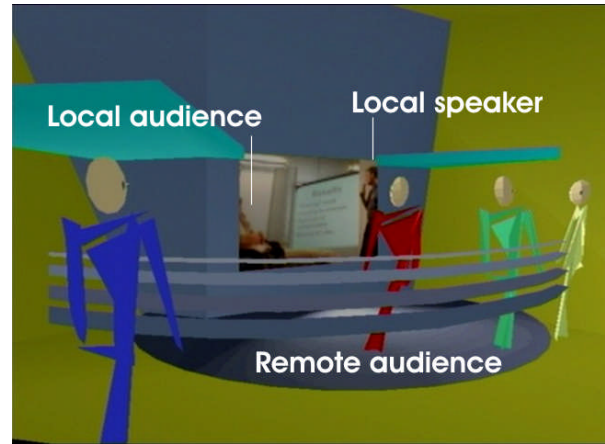
Figure 10 MRA for the local presentation

The physical audience now faced the other way in the direction of the physical speaker and the presentation slides that were projected onto a nearby physical screen (see Figure 11).



Figure 11 Local presentation: view from physical space

The virtual audience (now including the virtual speaker) directly faced the virtual side of the mixed reality boundary and the rails and markings in the collaborative virtual environment were automatically reconfigured to help them take up their new positions (see Figure 12).



**Figure 12 Local presentation: view from virtual space**

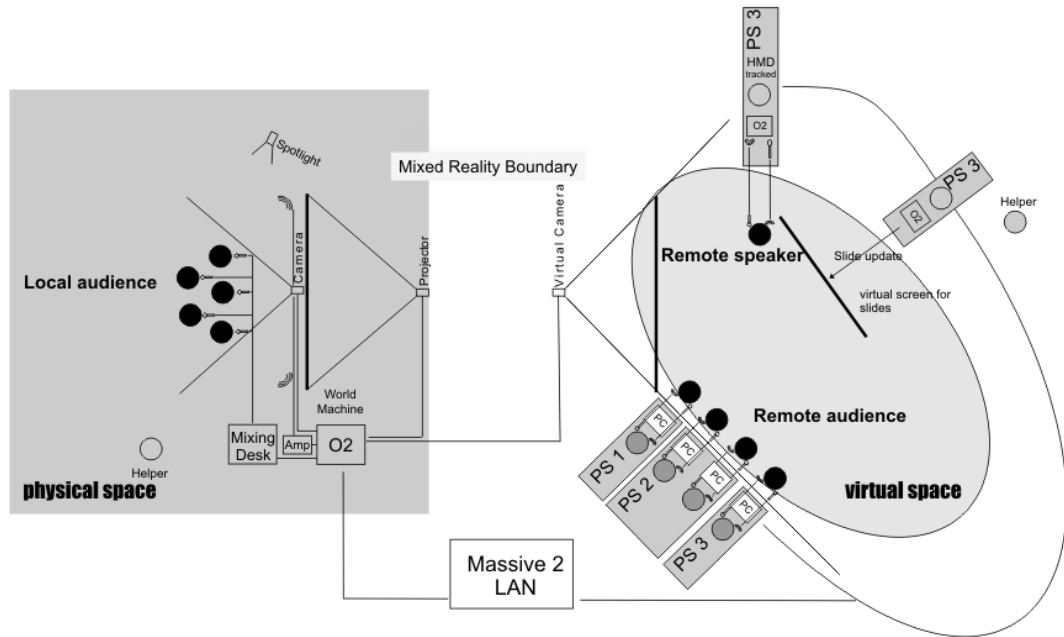
Again, a triangular relationship was established between the speaker and the two audiences, weighted towards speaker-audience awareness.

### 5.1.3 Technology

The virtual meeting environment was created using the MASSIVE-2 system (Greenhalgh and Benford, 1995). MASSIVE-2 was running on a server on the local network. The physical and virtual spaces were linked using a Mixed Reality Boundary (MRB) (Koleva, et al, 1999), effectively a MASSIVE client running on the same computer as the environment, creating a common mixed reality environment for participants in the study. The view that the MRB provided was back-projected on to a large screen with the camera mounted on a small stand in front of the screen and loudspeakers on either side.

The local speaker and the local audience members located in that space had access to handheld microphones that were connected to a mixing desk and then to the audio server of MASSIVE-2. Figure 13 shows the technical set-up for this part of the study, when the virtual speaker was presenting. Although there were changes to the layout for the physical presentation, the technical set-up remained practically the same.





**Figure 13 Virtual presentation: technical set-up**

The remote speaker and the remote audience members were located in three offices on a different level of the building. The remote speaker was more fully immersed in the virtual environment, wearing a head-mounted display and having real-time tracking sensors attached to head and both hands. The remote audience members accessed the collaborative virtual environment using desktop PCs and wearing headphone/microphone sets. They were physically dispersed in three office spaces in the same building. Remote speaker and audience members connected to the MASSIVE2 server across the LAN. During the experiment, the author supported people and technology in the physical presentation space, while Dr. Koleva supported people and technology in the office spaces.

## 5.2 Evaluation

The aim of this pilot study was to support distributed presentations by introducing a spatially integrated presentation space. The hypothesis was that this would have a positive effect on awareness even for the slightly larger audience sizes than have been reported previously. The intention was also to start exploring MRA in terms of its possible topology as well as its dynamics. Results from this experience were then fed back into the overall development cycle. Three methods

were employed in the evaluation: semi-structured interviews, a sketch map drawing task and an observational study using video recordings.

### **Semi-structured interviews**

Semi-structured interviews (see section 4.2.3) were conducted with participants and speakers. There were two sessions of interviews. Dr. Koleva's, the collaborator in this study, focused mainly on the level of awareness achieved. In addition, the author's own questionnaire was concerned with four different but interlinked areas of interest. The first set of questions was intended as a filter, attempting to identify people with little spatial awareness and/or little experience with 3-D computer environments. The second group of questions was intended to gauge the potential acceptance of the MRB technology in different settings. The third group of questions was aimed at gaining people's understanding of the architecture, while the last set attempted to gauge the level of awareness achieved in the system. The exact questions are listed in Appendix 11.1.2. They were asked as worded in the Appendix but when possible more information was probed for. Nine participants were interviewed since one participant was unfortunately not available for interview. From the interview responses a coding scheme was developed and responses categorised accordingly. The responses given are summarised in the appropriate sections below. The discussion that ensued during the semi-structured interview then brought to light additional issues and concerns that participants had. Of these, the most prevalent are summarised here, while full coded data set, including all the responses and the coding scheme can be found in appendix 11.1.3.

### **Sketch map drawing task**

As part of the interview, participants were also asked to provide a sketch map (see section 4.2.4) of the Mixed Reality Architecture. The specific instruction was as follows: *Could you please draw a map of the layout of the experiments including virtual and physical spaces?* All of the participants had access to the respective other side of the boundary before the experiment or at least before the drawing task. Participants were provided with a blank of A4 paper and a pen. No spatial cues were provided on the paper. This task was only introduced after two of the interviews had already been completed and the two participants were not available for re-interviewing. Therefore, only seven maps were obtained: two by virtual audience members, 1 by the virtual speaker and 4 by physical audience members.

The aim was to establish whether participants in this study did build up a spatial representation of the overall topology of the MRA and what this representation might look like. It was not clear what type of drawings to expect in this context as this method has not been used before for Mixed Reality applications to the author's knowledge. However, the inclusion or non-inclusion of elements and their topological relationship was what was of interest here. The analysis of the data is descriptive in nature, due to variations in the results and the small sample size. The collected maps can be found in appendix 11.1.4.

### **Observational study**

In addition, the pilot study was also recorded on video. This was supported by Dr. Fraser, a colleague at the MRL, who dealt with the technical and set-up issues of the recording process. There were 4 cameras in total. Camera 1 recorded the physical set-up from the left of the screen, camera 2 recorded the physical set-up from the right of the screen, camera 3 recorded an overview of the virtual side (audio missing) and camera 4 recorded what the projector projected (audio missing). All four viewpoints were also recorded jointly on a single tape that included all the audio material. In the case of the pilot study, these video recordings were used to cross-reference recorded events with the answers given during the interviews, as well as results from the sketch map drawing task. The recordings also provided additional material that was used in the evaluation.

### **5.2.1 Participants**

Ten volunteers took part in the study, of whom two were female. They were recruited from within the MRL but also included one guest researcher and two friends of MRL researchers. The participants' ages ranged from 20 to 40 years. Six of the participants had a background in computer science. None were involved in the development of the mixed reality presentation system. Eight of the participants were audience members (four made up the physically embodied audience, the other four the virtual audience). Two participants took the role of speakers – one for the virtual presentation and one for the physical presentation. Each speaker became an audience member during the other speaker's presentation.

A high proportion of the participants were familiar with computer games. Five stated that they played relatively regularly; one stated that they were familiar with them but did not play any more, while three participants never played

computer games. Similarly, as six of the ten participants used 3D environments for work, the proportion of people familiar with those was high, which probably resulted in the majority of participants, six out of ten, stating that they found them easy or quite easy to navigate. The table below summarises the results, while the full data set can be found in appendix 11.1.3

How often do you play computer games?		Do you use 3D environments for work (emerging from the discussion)?		Do you find them easy to navigate? (in the discussion it was made clear that this referred to 3D computer games and/or 3D environments as applicable)	
Never	3	Yes	6	Easy	1
Once a month	1	No	3	Quite easy	5
Once a week	1			With difficulties	2
A couple of times a week	3			N/A	1
Used to play. Familiar with them	1				

**Table 4 Experience with 3D virtual environments**

During the discussion, landmarks were mentioned most frequently as being used for navigation. Four of the participants also stated that the ease of navigation depended on the interface to that environment.

The self-reported spatial skills in terms of navigating new physical environments were also high (see Table 5). Seven participants stated that they found it easy or quite easy to navigate a city on the first visit. One participant stated that they found it difficult and one participant did not answer this question.

Do you find it easy to navigate in a city you visit for the first time?	
Easy	3
Quite Easy	4
Quite difficult	0
Difficult	1
Not answered	1

**Table 5 Spatial navigation in an unknown environment**

During the discussion, maps, landmarks and signs were mentioned as supporting the navigation process. However, four participants stated that the mode of transport would influence navigation. The results of the map drawing task concerning a map of Nottingham were dropped from the analysis. It was felt that through the fact that participants had very different levels of familiarity with Nottingham, this task did not provide a good measure for participants' spatial skills. When considering the above, it was clear that the participants were not representative of the general population. There is a clear bias towards males, expertise in IT (specifically 3D experience) and relatively young age.

### **5.2.2 Initial observations and reflection on design**

Generally the system performed well in supporting the chosen activity of presenting to local and remote audiences. Both talks were delivered and both sparked a question and answer session that involved members from the physical and the virtual audiences. The changeover between the two sessions was smooth. There were however a number of problems that should be addressed in future work.

#### **Support for spatial orientation**

The design of the virtual presentation space included markers on the floor and guides that were meant to help the speaker navigate to a position from where he would be seen by all audience members while at the same time having access to his slides. The speaker did however state that the guides were not very helpful and were sometimes in the way. One of the problems here was that the design tried to minimise the polygon load on the system. For this reason, all polygons were modelled as one-sided and were not visible from the other side. 'Collision detection' was also deactivated in MASSIVE-2 to save resources, which meant that participants could simply pass through any of the polygons. Another problem was that head movement in virtual space is generally much more restricted than in physical space so that markers on the floor for example were not necessarily in the participants' field of view and cannot therefore generally be relied on for virtual navigation.

#### **Participant representation**

The video texture worked well for the establishment of the identity of local participants. Their identity, body posture and 'general' facial expression were visible

on the video (see Figure 9). The people who were not known to the others already could easily introduce themselves by waving into the camera and saying their name. In the virtual space, avatars could only be differentiated by their colour. As already mentioned, they had no name tags or facial textures for example. Initially, this led to some confusion, when it came to addressing others. On the other hand this confusion also resulted in an interesting exchange right at the beginning of the study when participants discussed the identity of the avatars, when they matched avatar colour, voices heard and associated virtual movements.

### **Speaker interface**

The virtual speaker felt quite uncomfortable using the HMD and tracking equipment while giving his talk. The person who was asked originally to give the talk (an experienced HMD user) was unfortunately not available on the day of the experiment. Without this experience, the technology appeared to be in the way of the presentation and the speaker was somewhat struggling for example to get to a suitable position to start his talk. Originally, the HMD and tracking was chosen to allow the speaker a better sense of immersion and also to provide him with some form of body language. However, to make this work better in the future, more training of the speaker in the use of this type of equipment would be required. Alternatively, standardised virtual gestures and body language could be achieved with the use of keyboard commands as is customary in other virtual environments (Activeworlds, 2004) or omitted entirely, as these did not appear absolutely essential for giving a presentation.

### **5.2.3 Mapping MRA**

As part of the interview, participants were asked to draw the layout of the experiments. As mentioned previously, it was not clear what results to expect from this task, as this method had not been used previously for Mixed Reality applications.

#### **Elements drawn**

Maybe not surprisingly, it was found that participants tended to mention as well as draw elements that were important for the task at hand, in this case a presentation, and did not necessarily mention or draw the architectural layout in which these elements were contained. For example, the elements important for the

presentation like the presentation screen were drawn and mentioned, but not however the overall shape and organisation of the surrounding architectural space.

The architectural elements that were intended to structure the space in a way that would help participants navigate were either not 'hard' enough as in the case of the virtual space, where participants could traverse through the geometry at will, or were not noticeable enough as in the case of the physical line markers denoting the FOV in physical space. It seems that if a clear structure of the environment is required and intended to influence the behaviour of participants, architectural elements in a future version of the experiment would have to be made more explicit as well as 'harder'.

Architecture or an architectural layout seems to be most noted when it does not facilitate but hinders the activity people are engaged in. This pilot study was task based and architecture played only a facilitating role for that task. However, Mixed Reality Architecture does seem to have the potential, like physical architecture, to structure the conduct (e.g. navigation, behaviour through a presentation). For example, when virtual space was rotated into a new position, participants did move accordingly. The influence of the architecture on the outcome could have been greater, if certain elements (e.g. handrail, FoV denoters) had been made more obvious, collision detection had been turned on and all polygons had been made one-sided.

### **Preconceptions and assumptions**

Another notable aspect of the drawings was that one physical and one virtual audience member drew more of a map of the technological set-up of the experiment instead of an architectural layout (see Figure 14 below and appendix 11.1.4 (participant 8)). Both are researchers in the MRL and both left out virtual space in their maps (compare to Figure 13). When this was questioned during the interview, they both stated their own experience with the laying out of experiments and confessed to a slight misunderstanding of the question, as they thought they were meant to draw a diagram of the technicalities. The question might not have been clear enough and it might be interesting to try to structure the question better or prompt for very specific elements that participants are asked to draw instead.

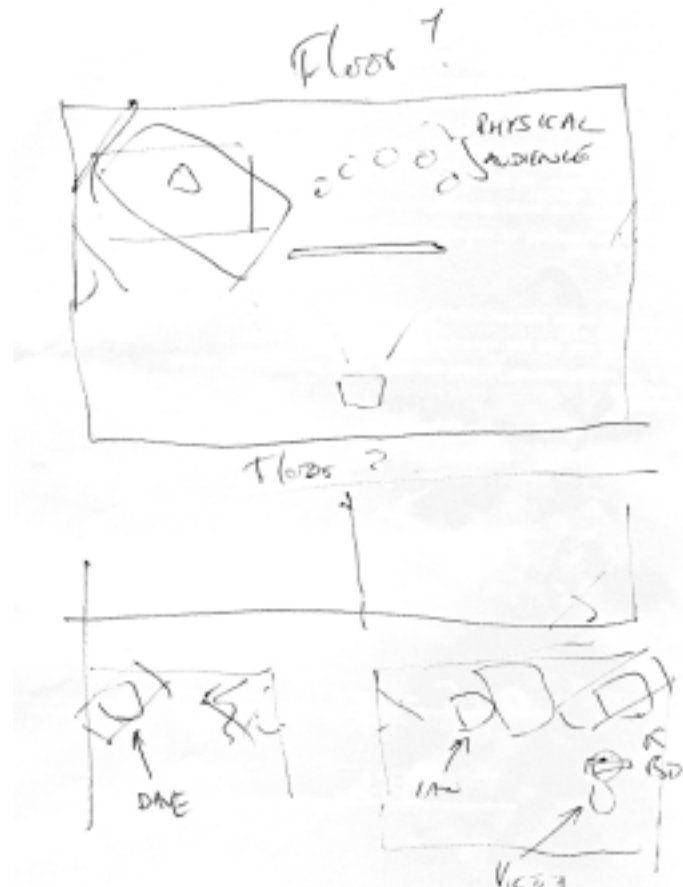


Figure 14 Drawing of experiment layout

#### 5.2.4 Acceptance of MRB technology

All nine of interviewed participants stated that they would consider the MRB technology for social interaction under certain circumstances. During the discussion, four mentioned that this was application dependent. It was also mentioned by four participants that it could not replace face-to-face communication or that it was unsuitable for deep social interaction.

Would you have the Mixed Reality Boundary installed at home?		Would you have it installed at the work place?	
Yes	7	Yes	5
May be	1	May be	4
No	1	No	0

Table 6 Acceptance of MRB technology at home and at work

Seven participants stated that they would consider an installation at home if the MRB was available (see Table 6). The discussions provided further information.



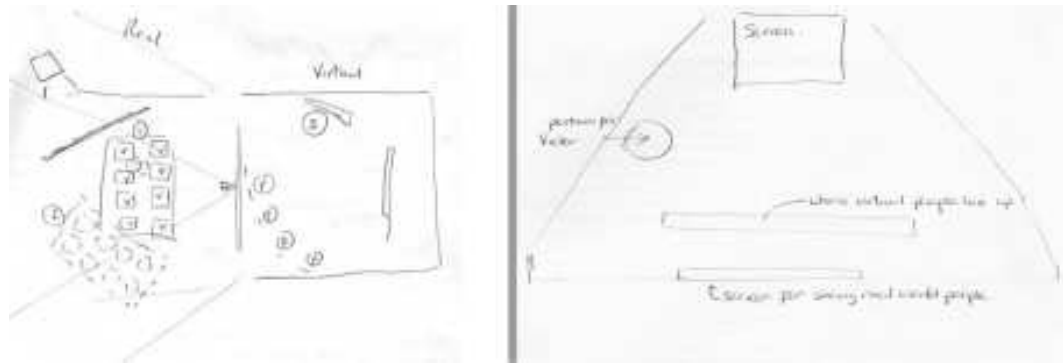
Three participants would use the MRB for communication and one each for recreation, community building and work at home. The factors that would influence an installation and were mentioned most often were privacy (two participants) and cost (two participants). Five participants stated they would consider an installation at work while four answered 'maybe'. During the discussion, two people stated use for group support as a reason. As stated before, the participants cannot be described as generally representative, but the data does point to the fact that the MRB might well be acceptable in certain circumstances. Some interesting comments were made concerning a comparison with the phone. It was mentioned that the MRB adds a common space (two participants) or adds human expression (two participants).

### **5.2.5 Spatial integration – co-presence**

Understanding the extent to which participants would perceive physical and virtual spaces as integrated was one of the main aims of this pilot study as it is a major factor in the support for awareness between all participants and the sense of co-presence people might have. The following analysis draws on data collected from all three methods.

#### **5.2.5.a *Sketch maps***

Regarding the integration of virtual and physical spaces, it was found that three participants drew the spaces on both sides of the boundary without being prompted (see Figure 15 (left) and appendix 11.1.4 (participants 4 and 9)). These drawings still contained noticeable mistakes, like the angle between elements for example. Two of these participants drew the sequence of these elements correctly. The fact that the three participants who did draw the spaces on both sides of the boundary drew a reasonably accurate representation of the architecture does point towards their understanding of the topology and also to their perceived integration of the two spaces.

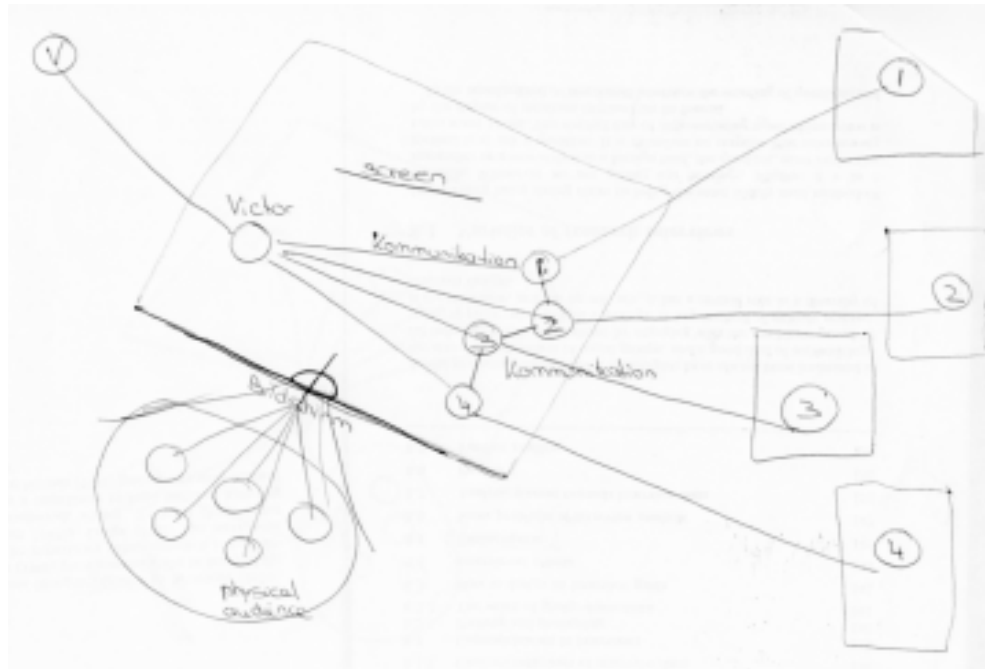


**Figure 15 Drawings of integrated (left) and segregated spaces (right)**

The two people (two virtual participants) who did not draw any representation of the physical side of the set-up (see Figure 15 (right) and appendix 11.1.4 (participant 5)), both commented on the image-like quality of the view into physical space and the poor quality of the video of that view. The physical side appeared more like a picture than a space (the texture did not exhibit any spatial properties). One participant mentioned that the position of the video texture with a large wall around it created a more dividing effect than was anticipated. It therefore seems that the integration of the two environments was hindered by the position as well as the properties of the boundary itself. The remaining two maps were drawn more in the form an experiment layout as discussed in section 5.2.3.

### **Unexpected drawings**

Two of the seven participants providing maps began to draw the set-up including local physical, virtual and remote physical spaces, in effect the whole MRA. From this it can be argued that these two participants did indeed perceive the different physical spaces and the virtual space as integrated. One example is shown in Figure 16 below. It was not necessarily anticipated that participants would draw the set-up in this way, and the fact that the others did not include the remote physical spaces suggests that the majority of participants did not see the remote physical spaces as integrated with the rest of the environment. There might have been a number of reasons for this. Great effort was spent on carefully preparing the layout of the local physical and virtual spaces but not much attention was paid to setting up the remote physical spaces. It would certainly have been better to separate all the virtual participants in physical space.



**Figure 16 Drawing of complete layout physical-virtual-physical**

Local constraints meant that the five remote participants were located in three office spaces, although wearing headphones separated them slightly more. At the same time a real-world situation would also not permit any control in this matter. Another point in this context however is that the types of interface were very different for local and remote audiences. While the local audience had access to a large screen display, the remote users were using desktop machines with considerably smaller and therefore less immersive screens. As these also did not have video hardware, local participants were not able to glance back into the remote physical spaces that virtual participants were located in.

#### **5.2.5.b Question about Integration**

Participants were asked whether they perceived the combination of virtual and physical spaces as integrated or separate. The specific question was: *Did the two spaces appear as separate, as extensions of each other, as one coherent space?* Three people stated that they considered the spaces to be separate. Two participants answered that the environment appeared as one coherent space to them, three answered that the two spaces appeared as extensions of each other. One participant said that the spaces appeared to be more coherent when the presentation took place on their side.

Did the two spaces appear as separate, as extensions of each other, as one coherent space?	
Separate	3
Extensions of each other	3
One coherent space	2
More integrated when presentation was on the side of the participant	1

**Table 7 Perceived integration of physical and virtual spaces**

The main factor in the way of integration on the physical side was the restriction of the FoV of the physical camera which meant that it was necessary to effectively place the remote audience slightly to the back of the local audience during the local speaker's talk. During the discussion, a number of other points emerged. For the virtual side, the poor quality of the video stream from the physical space had a detrimental effect on the perceived integration. Additional aspects here were the kinds of applications that are taking place, as one participant mentioned; and the likeness of the two environments, this having the potential to increase perceived integration, in the view of another participant.

#### **5.2.5.c Questions about Awareness**

To further evaluate the level of integration between the two environments, it was attempted to gauge how aware participants were of each other. A high level of awareness between participants located in physical and virtual spaces respectively would indicate an integrated space

The first question was aimed at the level of reciprocity of awareness that was offered by the set-up. Reciprocity of awareness describes the level of understanding of another participant's point of view. Physical space offers reciprocity of awareness and people often expect the same for any kind of conferencing system, when they expect others to see what they see and that the system acts in a symmetric way. Therefore, designing for reciprocity should make interaction between participants more intuitive. A great part of the design effort went into trying to insure that all the participants' perspectives were taken into account to make this possible.

The participants were asked the following question: *Were you aware whether others could see you across the boundary?* Six participants answered the question with yes,

one answered they were not sure, one answered no and one participant in the physical audience stated that it was clearer during the virtual presentation than for the physical presentation.

Were you aware whether others could see you across the boundary?	
Yes	6
No	1
Not sure	1
More so during virtual presentation	1

**Table 8 Reciprocity of awareness**

As reasons for their answers, two of the people who thought they understood whether others could see them, stated that the initial period of getting to know each other helped to clarify who could see what. Therefore, such a start-up phase might be useful or even necessary for novice users in future experiments. One person stated that the lines denoting the field of view of the physical camera helped them understand the configuration. None of the participants however mentioned any of the similar elements placed inside the virtual environment denoting the field of view of the virtual camera. This might mean that the elements were not distinct enough or that they were not important for the understanding of the layout. The participant (virtual) who stated that he was not sure whether others could see him, stated that during the remote speaker's presentation the local audience could see the remote audience but that that was not the case for the local speaker's presentation. He realised that that was probably wrong. Although the set-up was not completely symmetric it seems to have been clear enough for people to understand other people's perspectives. Reciprocity of awareness was therefore largely supported in the system across the boundary between physical and virtual.

Another measure of the level of integration is how well people were able to see each other and see the material presented across the boundary. This is clearly one of the prerequisites for perceiving the given environment as one coherent space. Two questions were asked to measure this and the first one was as follows: *Could you see the other participants at all times across the boundary?* One participant answered this question with yes, seven participants stated that they could see other

participants across the boundary but not at all times, one participant answered that he knew that they were there.

Could you see the other participants at all times across the boundary?	
Yes	1
Yes, but not at all times	7
Knew of their presence	1

**Table 9 Visibility of other participants**

As reasons why they did not see people at all times, two participants mentioned the poor video quality, three people mentioned the layout as the problem. Regarding the layout, participants mentioned two issues: during the remote presentation, tall people in the front row of the local audience blocked the remote audiences' view of others behind them, but more importantly, during the local presentation, the local audience was effectively sitting with their backs facing the screen. As they were sitting in one row, the view of some of them was again blocked. This was largely due to the constraints of the physical camera set-up (FoV and position of the camera). The comments on the video quality both came from remote audience members and do not refer to any problem with the structure of the layout as such. Participants were still able to see across the boundary and make out physical space on the other side but not with very good quality.

Could you see the material presented at all times?			
Physical audience members / Virtual presentation		Virtual audience members / Physical presentation	
Not clearly	3	Not clearly	4
Yes	1	Yes	0

**Table 10 Visual clarity of presentations**

The second question we asked was as follows: *Could you see the material presented at all times?* This question was aimed at both presentations for both audiences but what is really of interest here is the clarity of the respective presentations across the boundary. Three local audience members said the material of the remote presentation (by the virtual speaker) was not clear. Two of them stated the reason was that the presentation slides appeared to be too fuzzy; one of them said that the slides appeared to be at an awkward angle. All the remote audience members

stated that the material of the local presentation (by the physical speaker) was not clear. Three mentioned the poor video quality as the reason.

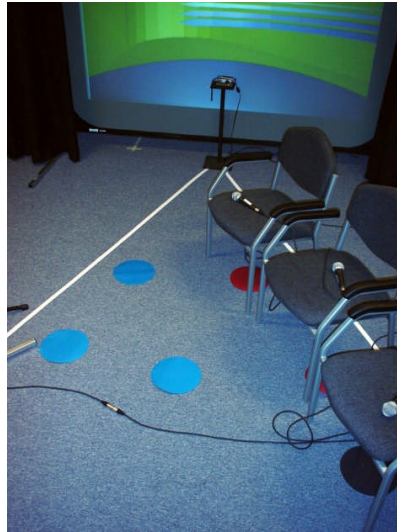
In summary it seems that the topology of the layout itself was appropriate in principle (two people explicitly stated that they could see that there was material but were unable to decipher it for example), however some elements of the technology were in the way. Two things that would need to be changed are the quality of the camera used, in terms of its field of view and associated position, and the quality of the video texture within virtual space. However, these issues do not imply a structural or conceptual problem.

#### **5.2.5.d *Observational Study***

The video material recorded provides further evidence for the spatial integration of the physical and virtual spaces. During the initial start-up phase, people were immediately aware of each other through the video and audio link provided. This is evident from the video footage when the conversation across the boundary started as soon as people had taken their places. For a while, the talk concerned the identity of the remote participants as already mentioned. But participants also helped each other to navigate to certain positions to ensure they were in view for everyone across the boundary. For this navigational task they used spatial language like 'move to the left' or 'move forward a bit' across the MRB, when they were trying to help others. The language used here is evidently spatial and this use of language seems to imply that the two spaces appeared as a coherent whole.

#### **5.2.6 Dynamics**

The architectural layout was changed in the middle of the study to provide an equally suitable set-up for both presentations. A detailed description of these changes can be found in section 5.1.2. In physical space this involved changing the direction of the audience's seats to face the physical speaker and slides. The original and new positions of the chairs were marked out on the floor as shown in Figure 17.



**Figure 17 Floor markers for different chair layouts**

One chair was taken away, since the local speaker used it during the remote presentation. Moving two ceiling-hung panels to the side, in effect enlarging the available physical space, revealed the physical presentation screen (see Figure 18)



**Figure 18 Chairs and screens in two different positions**

In summary, the main orientation of the physical space was changed while its position remained static. The size of the physical space was also enlarged.

In virtual space the change of the layout meant moving out of sight all the elements that supported the remote speaker. The podium, the markers for the speaker's position and the guides marking the position of the remote audience were all removed. This was achieved by animating parts of the architecture in a slow motion to make the change apparent and experientiable. In replacement for these elements a new marker on the floor was slowly moved in. Also, a new guide shaped like a series of arrows was rotated in from the back, slightly 'pushing' the avatars into a good viewing position for the virtual presentation. Figure 7



shows the virtual space before the changes while Figure 10 shows virtual space after the changes.

### 5.2.6.a Sketch maps

It was expected that these changes, or more precisely the result of these changes would be represented in participants' sketch maps of the pilot study MRA. However, two participants drew only one set-up in the beginning and only after being prompted to do so would they draw the second one. Three participants drew both set-ups in one drawing and two participants made a clear distinction from the outset (see Figure 19). In summary, the majority of the subjects did not distinguish clearly between the set-ups.

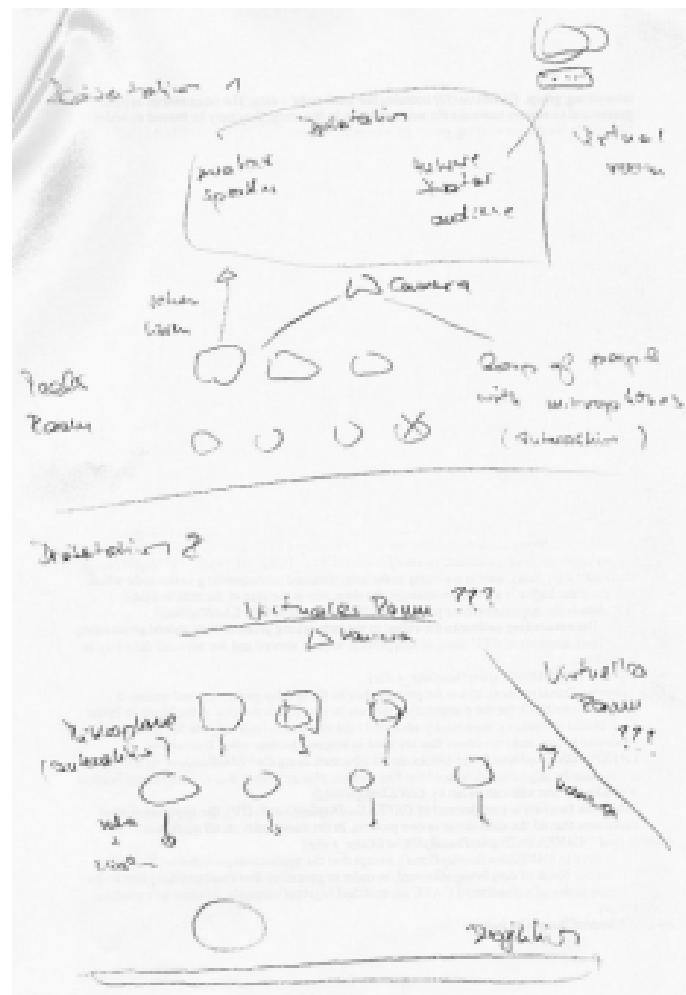


Figure 19 Drawing of both set-ups

It is only possible to speculate as to the reasons for this. It might be that the difference between the two set-ups was not great enough to be remembered or it might simply be a rather difficult set-up to ask people to remember. Also point-

ing to this could be that all the drawings contained mistakes. This extended from minor errors like the wrong number of participants to more major ones when the relationships between the separate elements (e.g. MRB, speaker, presentation screen, audience) were drawn incorrectly.

It can also be argued that the distinction between the two separate environments was not relevant for attending the two different presentations, as participants mainly concentrated on the subject of the talks. Therefore the change of the environment might have been noted while it was taking place (animation of virtual space, changing layout manually in physical space), but it might not have been important enough to remember.

#### 5.2.6.b Questions regarding Dynamics

Participants were also asked whether they thought the MRA was suitable for the tasks at hand. The exact question was: *Was the spatial layout suitable for both: presentations and Q&A sessions?*

Six of the audience members stated that the overall set-up was suitable for both presentations and Q&A sessions, one physical audience member said that it worked for the virtual but not for the physical presentation while one participant mentioned that they considered it ‘neither suitable nor unsuitable’.

Was the spatial layout suitable for both: presentations and Q&A sessions?	
Suitable for both	6
Neither suitable nor unsuitable	1
Suitable for virtual presentation but not for the physical presentation	1
Missing response	1

**Table 11 Suitability of the spatial layout**

Participants were also asked whether they understood the change in topology and the reasons for the change. The question was posed as follows: *Did you understand the change of the topology of the architecture and why it changed?* Five people stated that they understood the changes; one participant could not give a reason for the change while three people either missed the changes or could not remember them.

Did you understand the change of the topology of the architecture and why it changed?	
Yes	5
No	1
Missed changes or don't recall	3

**Table 12 Understanding the topological dynamics**

Unfortunately there is little data on whether the changes helped orientation as participants did not answer this question fully. The following question was posed: *Did that help you navigate?* (Referring to changes in topology). One person stated that they helped, one person stated that they did not help orientation and one participant stated that they were told where to go but that it was also fairly obvious.

In summary, the questionnaire responses show that the two separate layouts were suitable for the presentation and understood by a majority of the users. Whether they directly helped participants orient towards the two presentations is unclear from the questionnaires.

#### **5.2.6.c Observational study**

The recorded video shows that two members of the remote audience reacted with surprise to the change in the virtual environment. Although the change was clearly visible on the MRB and was triggered before the physical set-up was changed manually, the physical audience members did not react but watched silently. While the remote speaker was taking off his immersive equipment, three of the remote audience members followed the new virtual guide as intended to a suitable position for following the physical presentation. The fourth remote audience member left the virtual room and was out of sight for a short period. This they probably did not realise because of the one-sidedness of the polygons, as their view into the virtual presentation space would have been unimpeded. They moved in closer soon after the changeover. After the change was complete, all four remote audience members had changed position from the right of the screen to the centre, which offered the best view of the physical space. They were located inside the new guide and on the marker on the floor. The physical audience was then prompted to get up to allow the changeover of the positions of their seats. At the same time the panels hiding the physical presentation screen were

moved out to the sides. The microphones were taken off the seats and the seats were moved to their new positions marked on the floor. The physical speaker then prompted the audience to take their seats again. The physical changeover could clearly also be observed from the virtual side and three of the virtual audience members were facing the MRB during this time, presumably watching what was going on in physical space. All this shows that the changes within virtual space did indeed prompt participants to move to new positions within the virtual presentation space.

### ***5.3 Driving forward the design of MRA***

The pilot study was broadly successful in demonstrating that Mixed Reality Architecture could be used for distributed presentations. The presentations by local and remote speakers to a mixed local and remote audience were well supported, although they were not without difficulties. These and the question and answer sessions that followed showed that presentations to medium sized audiences at least can be well supported within MRA in principle. However, in terms of driving forward the research presented here, a number of other, more fundamental issues were more relevant. These will be briefly reflected on below.

#### **Design**

The design elements intended to support orientation within virtual space were only partly successful and occasionally even in the way. It appeared that they were of too small a scale to be noticed and unintentionally outside the FoV of participants, when they were most needed, as participants were for example not able to look straight down at the floor. In addition, the single-sidedness of polygons and the lack of collision detection in a comparatively small virtual space lead to navigational difficulties. For physical space, no such problems were obvious, while there was of course a lot less navigation and positions were more clearly defined in the form of the audience's seating.

#### **Representations**

The representations of the remote audience also had clear problems. Although the initial conversation among participants quickly got over this, the identity of remote participants, their body language and facial expressions could not be read by others. This could potentially be improved with better avatar design and a

better interface for controlling those avatars. On the other hand, the MRB technology offered real advantages here, although the video quality was relatively poor. Furthermore, to use immersive technology (trackers and HMDs) for participant interaction would clearly require participants to be trained up and experienced enough to be able to concentrate on the task at hand instead of the technology itself.

### **Integrated space**

The MRA of this pilot study did establish an integrated Mixed Reality space, at least between the two presentation spaces, and a sense of co-presence between local and remote participants was established. Very broadly, the MRA appeared more integrated to people who were part of the local audience with access to the MRB compared to members of the remote audience, who used desktop machines. The remote physical spaces (the physical locations of the remote audience members) did not seem to be integrated however with the rest of the environment, while this was not an explicit aim of this particular study.

### **Dynamics**

This pilot study introduced a particular, very limited type of dynamic topology. It was controlled by the experimenters and occurred only at one particular point in the experience. It was used to adapt the MRA to exactly two states of activity: the remote presentation and then the local presentation. In this context, this adjustment worked well and provided a suitable framework for the two distinct activities. However, adaptations in physical space were relatively slow and some form of automation or a better interface to restructuring might be useful in a future experiment, if physical adjustments were needed.

The available dynamics were clearly designed to be suitable for one particular event: the study described in this chapter. This event followed certain rules. It was tightly scheduled and occurred at a particular time and particular places to which all participants had to attend. The social relationships between different actors were very specific such as the relationship between the speakers and the audience: the speakers would give a presentation facing the audience during which audience members remained silent. This was followed by a question and answer session where participants and speakers took turns during a discussion. These social relationships were then deliberately translated into very specific spa-

tial relationships: the two parts of the audience and the speaker have been arranged in a triangle with the position of the speaker slightly favoured.

Hillier has termed spatial relationships that are subject to such specific rules 'long models' (Hillier, 1996). He points out that long models introduce specific local but also global rules that restrict the possible topologies of architectural cells within architectural configurations, whether this is within buildings or urban space. In this way, the resulting spatial configurations are to a large extent reflections of the underlying rules, which is of course exactly what occurred in this pilot study. Although its MRA was dynamic, to allow for the two separate presentations, the dynamic adjustments were also clearly limited as this was what the occasion required. In this sense the pilot study was similar to a physical building. The social interface between speakers and audiences was clearly defined, and it was expressed spatially in a particular way, very similar to a physical auditorium for instance. Yet, in contrast to physical buildings this social interface had two spatial orientations: focussing first on the virtual speaker and then at the physical speaker. Reflecting on this, it became clear that to investigate dynamics in architectural configurations fully, it was necessary to consider social occasions that follow a 'short model', where social and spatial relationships are prescribed to a much lesser extent.



## Mixed Reality Architectural Cells: extending the framework

This chapter details the design considerations for the second major phase of prototyping Mixed Reality Architecture. It builds on the previous chapters by expanding the general framework of MRA with the key concept of Mixed Reality Architectural Cells (MRACell). Having an emphasis on building architecture, MRA is designed to link physical spaces (public and private) rather than individual people. These links are embedded in a virtual spatial framework that is designed to make remote social interaction within it available or legible to others. Spaces are linked in a dynamic way that allows stakeholders in the system to re-configure connections on the fly, and those connections are represented externally to others. This makes it relevant in an architectural sense as the topology of physical architecture is generally very rigid and cannot be easily adapted, which

often becomes a problem for larger organisations spread across multiple physical sites. The following design considerations are based on the original framework but also draw on the experience with the pilot study.

## ***6.1 Application domain***

For this main study, MRA was investigated within a different application area. For this phase the intention was to move away from short-term experiments to be able to study MRA in more detail. It was felt that only then could the concept be fully explored. To allow this to happen, a group of people had to be identified who were available and willing to participate over an extended period of time, and an application or task area had to be chosen that would support these people in their everyday activities as only then could extended use be expected. The Mixed Reality Lab (MRL) itself was selected as an ideal test bed for MRA, as participants and technology would be available long term. The organisation of the MRL has already been described in sections 4.1.1 and 4.1.2. For a more detailed understanding a survey concerned with informal social interaction was also conducted. This will be described in section 7.1. The above taken together makes clear that the spatial distributedness of researchers within the MRL, including collaborators from other research institutions, has led to a lack of informal interaction, widely identified as crucial for work.

It was therefore decided to design and then introduce an MRA into the MRL that would support informal social interaction, awareness, communication and collaboration between people physically not co-located for the long to medium term. This type of social interaction follows a 'short model', where social rules and spatial configurations are not entirely pre-specified (Hillier, 1996), and it is of course an area that has been investigated previously with a wide variety of different technological approaches, as has been mentioned in section 2.3. To be able to respond to participants' requirements during the development phase, this MRA was developed and deployed in stages, in line with the overall prototyping development process.

As the concept of MRA entails linking multiple physical and virtual spaces in a dynamic way, this would require multiple interfaces between those spaces. For the reasons mentioned in the previous chapter, the Mixed Reality Boundary



(MRB) was chosen as the only interface technology. Bringing together multiple MRBs in this ways made it necessary to address a number of interrelated issues. MRBs had to be represented in virtual space, as a representation of their owners and the spaces themselves. An interface had to be found to arrange these in virtual space and allow owners to change that arrangement on the fly. A mechanism had to be designed to deal with the fact that these links are embedded in two distinct spatial frameworks: physical and virtual space. This is particularly important as the intention was to design MRA for an everyday setting with other activities taking place in the same physical topology in which MRA was going to be placed, and to study it over the medium to long term.

The concept of architectural cells introduced at the beginning of the literature review provided a good starting point for the re-design of Mixed Reality links as part of MRA. What follows is the reiteration of the concept of architectural cells, the introduction of the concept of Mixed Reality Architectural Cells (MRACells), the selection process of physical spaces for setting up MRA and the topologies that can be created with the use of MRACells. This in turn is followed by consideration of the representation of participants in MRA and the representation of MRA as a whole.

## ***6.2 Architectural cells: co-presence***

The smallest architectural space possible is the elementary architectural cell. It is a fundamental architectural concept and is as it were the smallest building block of which any architectural structure consists. The literature review has already introduced this concept and the following serves merely as reminder of the main issues. Simmel describes the process of segmenting a cell from continuous space and its subsequent linking back to that continuous space through doors and windows (Simmel, 1909). Hillier & Hanson describe the accumulation of architectural cells into larger structures and the local rules that are responsible for this global effect. They argue that one important function of architectural cells is the establishment of the categories of inhabitants, strangers and visitors (Hillier and Hanson, 1984). Price proposed the Generator project consisting of mobile physical cells that would be assembled according to the needs of inhabitants, with the building learning over time what might be required (Price, 2003). Benford et al describe the aggregation of physical and virtual cells into tessellated mixed reali-

ties, those spaces being linked together by Mixed Reality Boundaries (MRBs) (Benford, et al, 1998).

Another function of architectural cells is to establish co-presence between two or more people who are located within it at the same time. Again this is a fundamental function of architecture: structuring co-presence within physical reality. This is achieved by placing people within the boundaries of the same space. Avoiding issues of design, form or scale this leads to the following definition of architectural cells as used within this thesis: an architectural cell is defined as a spatial unit in which people are co-present and have a symmetrical relationship to each other in terms of their potential for social interaction. For example, a simple unpartitioned square room would be included in this definition while an L-shaped room must be regarded as constructed of two spatial cells.

This definition also allows the inclusion of virtual three-dimension cells both separately and also in combination with physical architectural cells. Although it is clear that current interface technology has a significant (mostly negative) impact on co-presence when compared to physical spaces, three dimensional virtual spaces have been designed to at least simulate co-presence between its inhabitants (see framework in chapter 3) and the same applies to architectural cells 'carved' out of that virtual space. Virtual architectural cells as set up by the architects of an environment or by the inhabitants themselves then serve a very similar purpose, by controlling access and establishing the categories of strangers, inhabitants and visitors.

More relevant in the context of this research are considerations of the effect of joining physical and virtual architectural cells directly together via a Mixed Reality Link. The adjustment of the properties of the Mixed Reality Link for access control in addition to the adjustment of what can be perceived across such an interface have been explored previously (Koleva, et al, 1999). Here a different approach is being explored, which is not based on the interface technology as such but rather on the use of additional architectural elements just like in physical architecture.

### ***6.3 Mixed Reality Architectural Cells***

As a result of the discussion above, the concept of Mixed Reality Architectural Cells (MRACells) has been developed. MRACells are defined as spatial units consisting of one physical and one virtual spatial cell joined together by a Mixed Reality Link. MRACells form the basic building blocks for the creation of Mixed Reality Architecture.

Those cells are conceived as being permanently attached to each other. Based on the aforementioned definition of architectural cells, they are also designed to support co-presence between inhabitants who are physically or virtually present within them. The aim is to maintain as symmetrical as possible a relationship between people present within an MRACell, given that this will clearly be influenced by the actual interface technology used.

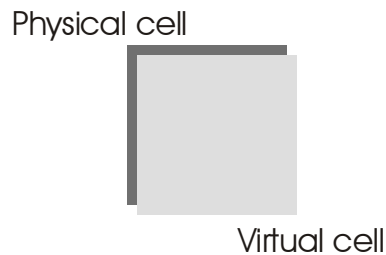
Practically, each physical cell is associated with a virtual cell that is equivalent in terms of the access control it affords. The owner or owners of given MRACells have the right and tools to change the quality of access on three different boundaries. Firstly, there is the physical access to the physical space. This is usually controlled with a door in addition to windows controlling visual access only, just as in any typical room. Secondly access to the virtual side of the MRACell must be controllable and this can be done with very similar architectural elements, depending on the actual design, effectively creating a virtual door to the virtual cell of some description. Finally, it would also be possible to control access across the MRLink separately as Koleva et al have shown in detail (Koleva, et al, 1999). The three access controls could of course also be combined.

Before going into more detail about the actual design of MRACells, another issue is of importance: the spatial relationship between physical and virtual cells. In what way they are conceptually linked is, in the first instance, a design decision and secondly dependent on the interface technology chosen. In the following very much simplified description, different ways of overlaying physical and virtual cells will be discussed. The surrounding physical and virtual spaces have been ignored at this point but will be covered in section 6.4.

#### **Directly overlaid**

Physical and virtual cells can be directly overlaid. Entering one cell then also means entering the other one. This is the approach taken by a number of mixed

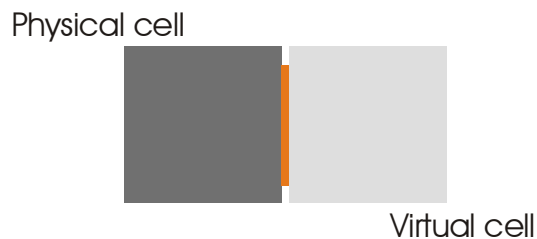
reality systems (Anabuki, et al, 2000), (Feiner, et al, 1997) and is consistent with the MRA topology described in section 3.3.4.a. Generally, physical space is seen as primary and is then augmented with digital information.



**Figure 20 Physical and virtual cell directly overlaid**

### **Discrete**

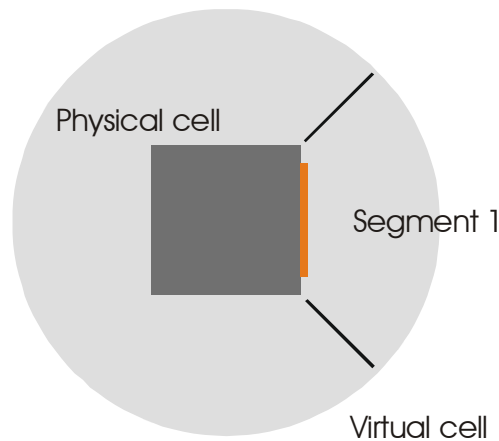
The two cells can be set up to be discrete. Entering one cell then means crossing into the space containing the link to the other cell. The Mixed Reality Boundary technology best represents this approach (Benford, et al, 1998). This is consistent with MRA topology described in section 3.3.4.b.



**Figure 21 Physical and virtual cell discrete**

### **Embedded**

Another possibility would be to embed one cell inside another cell. The figure below shows a physical cell embedded inside a virtual cell, effectively cutting it off from physical topology. Segments of this 'virtual bubble' would then allow access to the link on one particular side of physical space and multiple links into virtual space can be established in a similar way to the CAVE system (Cruz-Neira, et al, 1993). Equally, embedding a virtual cell in physical space is also possible, by simply creating a virtual CAVE, where views into physical space are digitally mapped on to the sides of a virtual volume.



**Figure 22 Physical cell embedded inside virtual cell**

Embedding architectural cells within each other has elements of the previous two concepts. On the one hand, embedding one cell inside another means that the two cells are at least partly overlaid. On the other hand, when it comes to implementing version three without the use of a CAVE, it effectively becomes a discrete arrangement of the two cells, if for example only one segment is used (see Figure 22).

### 6.3.1 Early design of MRACells

To explore these ideas further they were first prototyped in a modelling package and then within MASSIVE3, the CVE platform to be used. This happened as a first stage of the development process: the result is shown in Figure 23 and Figure 24 below. The upper part of the images contains the main view into the MRA as seen from a physical cell across the attached virtual cell into virtual public space. The small window in the bottom right displays a map of the entire environment while in the top right corner the video of the physical part of this MRACell is being displayed.

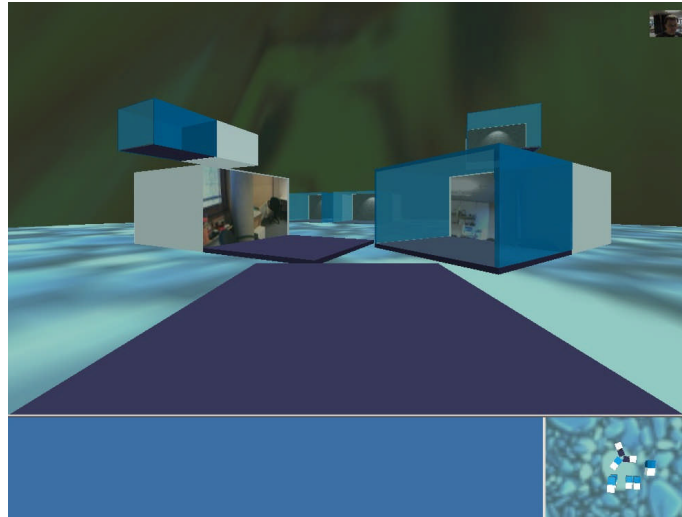
Each of the MRACells consists of two parts: a physical cell and a virtual cell. They are attached to each other by an MRB and are represented differently in physical and virtual public space. In physical space they are represented by their actual physical cell (a room for example) with the attached virtual cell being projected on the projection screen of the MRB. As part of the MRB technology, camera, microphone and speakers are also set up in appropriate places. In virtual space, virtual and physical cells are both represented with 3D geometry as one element or MRACell. Live video taken from the physical cell is mapped on to the

front of the representation of that physical cell. Live audio captured from the physical microphone is mapped to its virtual position. This makes use of the MRB technology described previously and allows connections back into other physical cells that are connected via other MRACells.

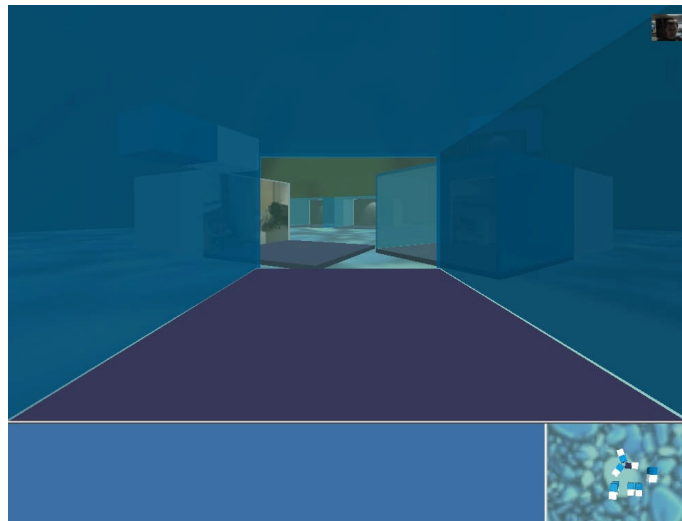
Each inhabitant/group of inhabitants owns and controls the access to one MRA Cell. There are two types of control. Firstly, inhabitants control the position of their MRACell in virtual space, which in turn affects the overall topology of MRA. This will be discussed in detail in section 6.4. All the usual controls to movement within virtual space are available. Using MASSIVE3's spatialised audio, when two MRACells are virtually close to each other a live audio connection is opened in addition to the video becoming clearer, simply as a function of the reduced distance between the two cells. Inhabitants can therefore create spatial configurations according to their requirements and by moving around (not unlike repositioning a camper van on a campsite or house boat in a marina) they can establish social interaction between different MRACells across virtual public space.

Secondly, inhabitants also control access to their MRA Cell both from public physical space or public virtual space, and access across their own MRA Link. This is achieved by controlling the boundaries to a particular Cell. Boundaries can be closed, opened or removed altogether. This is the rationale for the separation of the physical from the virtual spatial unit within an MRACell, as entering one does not now automatically allow access to the other, as long as more fine grained controls are implemented at the level of the MRLink. MRA Cells are designed to allow protection of private property and social interaction from the interference from strangers, very much like physical architectural cells.

Figure 23 shows a first person view of an MRACell in its open state, the floor of its virtual cell visible in dark blue, stretching out into virtual public space. Other MRACells are clearly visible in the background, with the one on the left displaying a view back into another physical cell. Figure 24 shows the same MRACell in its semi-closed state. The virtual cell has been designed as a simple box, with an opaque floor and transparent sides and ceiling.



**Figure 23 MRACells - first prototype (open)**



**Figure 24 MRACells - first prototype (semi-closed)**

In its semi-closed state the virtual part of the MRACell limits visual access in both directions. From the physical cell access to virtual public space is restricted. At the same time access from virtual public space to the live video streamed from the physical cell is also limited. The virtual cell therefore acts as a door or gateway controlling access to the MRB interface itself. It was designed to enforce close virtual proximity between cells, before any visual contact between physical spaces could be established, but also to allow two MRACells to be configured so as to prevent a third party being able to watch without being noticed.

During early testing it became clear that there were a number of problems. Rendering two views into the MRA, main view and map view at the same time was not viable in terms of rendering performance. In addition, the two windows were not integrated, which caused problems in terms of mouse focus and visual clarity

as the desktop beyond was also still visible. The re-design of this part of the interface is described in section 7.2.3. More fundamentally however, the design of the virtual cells themselves did not provide any indication of the FoV of the virtual camera. It was felt that this would make the alignment with others unnecessarily hard and would also allow an asymmetry between MRACells when the inhabitants of one could see the inhabitants of another without themselves being seen.

### 6.3.2 Design for the situated prototype

The MRACells were therefore re-designed. What is shown Figure 25 is the design as used in the final prototype, after a number of minor alterations had been made. The virtual cell was now shaped exactly in the form of the FoV of the virtual camera with an opaque floor and semi-transparent sides and ceiling. To allow complete privacy, a closed state was added to the two other states mentioned previously. Figure 25 shows a third party view of the three possible states. In the open state the side panels were designed to allow others to infer what the inhabitant of a particular MRACell could see of their surroundings and then position their own MRACell accordingly, either to prevent visual access or to allow it.

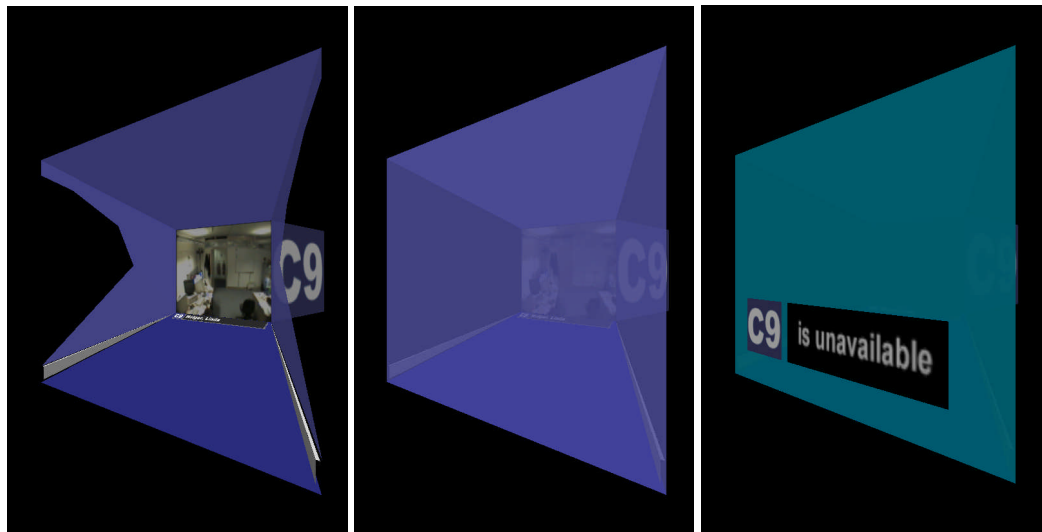


Figure 25 MRACells: open, semi-closed, closed

The semi-closed state then provided low quality visual access to the live video texture with the aim of allowing others to see whether somebody was in the physical space at all. It was also designed to allow owners of a cell to express that they were in their physical location but might not be available. Finally, setting the MRACell to its closed state provided the maximum amount of privacy. The



polygon holding the live video was taken out and replaced with an empty one and the outside of the virtual cell clearly displayed that the inhabitants were not available. The idea was that inhabitants could display that they were currently not in the building or really did not want to be disturbed.

## ***6.4 Topologies that can be created***

The two general topologies of MRA have already been discussed in section 3.3.4. With the aim of establishing spatial flexibility between physical and virtual topologies, the second type was chosen: no spatial relationship between physical and virtual topology was specified. What follows is an outline of the concrete topologies that can be created with MRACells.

There are two distinct spatial frameworks that Mixed Reality Architectural Cells are embedded in: the relatively static physical topology of the physical rooms in which the MRBs are located and the relatively flexible virtual topology generated as part of the MRA.

### **6.4.1 Physical topology**

Physical architectural cells can be described as being linked by or embedded within physical public space. This would for example be through adjacent corridors or open spaces outdoors. Through these any physical architectural cell can be reached in principle, although this might require considerable time for travel.

This introduces a topology that consists of private and public areas, since by definition separating cells from the space around them means controlling the access to these cells. There are rules in place according to which members of the public are granted or refused access and these rules are typically enforced by physical boundaries between private and public spaces but also by social rules and customs. For example, a home space allows very limited access while office cells are much more public. At the same time these cells are already linked via the telephone and computer networking with this link being very flexible but despatialised as already discussed.

This physical spatial topology is more or less fixed. Occupants of physical buildings do not generally have any means to make spatial changes to their surroundings apart from very limited ones. To be able to interact with others

present in this topology, co-presence has to be established between at least two people and this means that those have to be present in the same spatial cell, as defined here.

### **6.4.2 Virtual topology**

Virtual architectural cells are embedded within the virtual public space of the environment that the associated MRACells are connected to. This virtual public space might have a similar structure to physical space with private and public areas in a certain configurations, or it might be entirely unstructured, only providing a backdrop for the connected virtual cells. The access to virtual cells themselves can be controlled according to their privacy requirements with the architectural means already described.

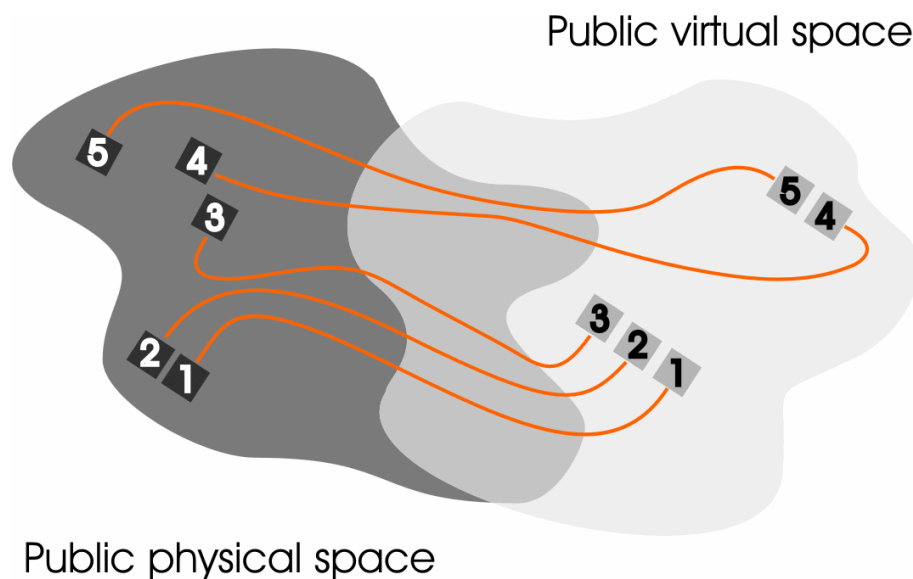
In contrast to physical space, this topology is very flexible. Inhabitants of MRA can adjust the virtual topology by moving their own virtual cell as attached to their MRACell around within the virtual spatial framework. Their virtual spatial position therefore becomes a communication tool in an application of the spatial model of awareness (Benford and Fahlén, 1993). However, now it connects architectural spaces with all their inhabitants to each other rather than just individuals. Instead of moving individually, as in physical space or indeed within the typical CVE, inhabitants now move their virtual cells to establish co-presence with others who are not physically present, and this incidentally also establishes co-presence between all others present in the MRACells concerned, allowing them to interact socially.

### **6.4.3 Dynamic topology of MRA**

Through the combination of the two topologies above, an entirely new architectural topology is made possible: the dynamic topology of MRA. Any movements of virtual cells within virtual space also indirectly affect the otherwise static physical topology, when links are established between physical spaces that are not co-located. New dynamic architectural designs are therefore created on the fly by inhabitants. The movement of individual MRACells within virtual space then allows the dynamic configuration and re-configuration of the overall topology of MRA and with it to a certain extent that of physical space. The two figures

below serve to illustrate that process in a more detailed fashion than in the framework (see section 3.3.4).

Figure 26 shows five MRACells. Their physical parts are embedded in static physical topology and they are linked to their virtual equivalents via an MRLink, here depicted with orange lines. MRACells 4 and 5 are arranged in such a way that their virtual parts are facing each other, allowing people present within them to interact socially. This brings the physical cells 4 and 5 close together, although they do not have to move physically. MRACells 1, 2 and 3 are arranged in a line, facing the interaction between MRACell 4 and 5.



**Figure 26 MRA Topology 1**

In comparison to this, Figure 27 shows that the virtual cells MRACells 1 to 5 have now been re-arranged. MRACells 1 to 4 are now arranged in a quadrangle, while MRACell 5 is separate from this group. People present in MRACells 1 to 4 can interact socially, while people in MRACell 5 are too far away. This second topology brings the physical cells 1 to 4 close together, although they have not moved physically.

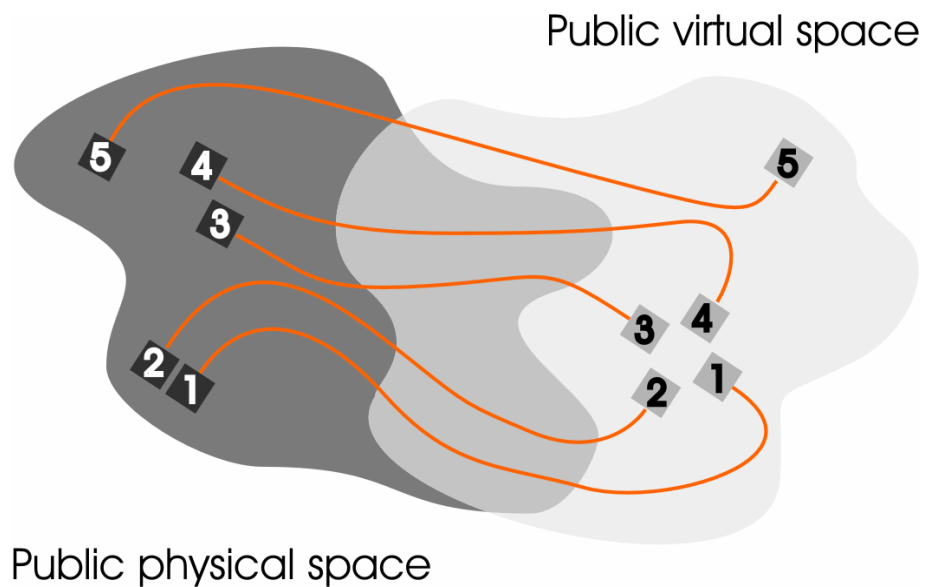


Figure 27 MRA Topology 2

More concretely, the above configuration of four MRACells arranged in a quadrangle as seen from within virtual public space is shown in Figure 28 (note that this depicts four identical MRACells).

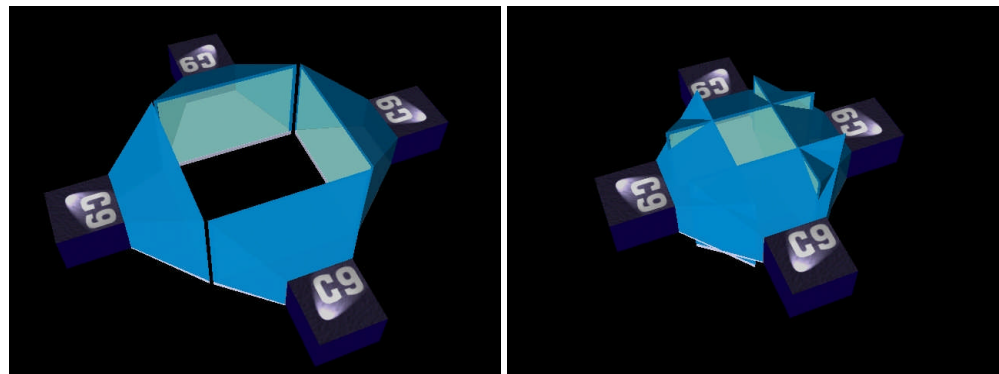


Figure 28 Four MRACells in wide and close quadrangle arrangement.

On the left of the figure, the MRACells are spaced further apart, while on the right they have come closer together, preventing others from joining the meeting. As mentioned previously, these movements are all controlled by the respective inhabitants.

## 6.5 Physical location of MRACells

Suitable physical spaces now had to be chosen, in which MRACells could be set up, first within the setting of the MRL but then also at remote sites, once MRA had expanded to those. There were a number of issues that needed to be considered when choosing the location and type of set-up for each MRACell.

Firstly, the choice of space for setting up an MRACell was mostly dependent on the willingness of its occupants to participate in the study over the medium to long term. Interested and enthusiastic people had to be found who were likely to want to use MRA frequently enough to be able to study the system in use. Secondly, the spaces chosen had to be analysed in terms of their everyday use, and possible private and public areas within them had to be identified. This then had an effect on link placement within these spaces with a particular regard for the effect on circulation. The quality of the space also had an effect on the choice of camera lens for a suitable FOV, as well as camera placement and orientation. It was important to check what inhabitants could see from their everyday vantage points and what others might be able to see of them once linked into MRA. Related to this, the effects of having an open microphone placed in the space had to be discussed as this could result in audio being transmitted involuntarily. This might well be an issue in terms of privacy, but could also disturb others when they are virtually close by. Thirdly, spaces were analysed in terms of who had ownership of and control over them, to decide how this could be modelled inside the system and whether it could be expected that someone would feel responsible to deal with any problems occurring. Finally, camera placement on the screen was an important issue. To allow people to look at the MRALink and be seen by others, the camera must be on the screen pointing away from it. Eye contact requires a camera position in the centre of the screen although that is particularly difficult to achieve (Ichikawa, et al, 1995). There was also the issue of how the FOV of physical and virtual cameras could be represented to inhabitants to allow them to choose whether they wanted to be in view or not.

Five types of possible spaces were identified at the Mixed Reality Lab (MRL) that had varying degrees of privacy requirements. The choice of cells is based on the typical working relationships within an office environment.

### **Single office**

The standard working space for permanent staff is a single office. The size of the office varies with seniority of the staff member. Here individual control, ownership and use of an MRACell could be studied.

**Shared office**

The standard working space for research students and research staff is a shared office. Occupancy is between 2 and 8 depending on the size of the room. Here shared control, ownership and use of an MRACell could be studied.

**Meeting rooms / lab spaces**

There are a number of semi-public meeting and lab spaces located in the MRL. They are only temporarily occupied and sometimes also act as circulation spaces. Here control and ownership of any MRACell could be said to be undefined, making it also interesting to study.

**General circulation spaces**

On the floor above the main lab space of the MRL, there is a corridor that links associated offices. There is a second corridor linking the offices of senior staff on the same floor as the main lab space. In addition, there is the general staff room of the Computer Science department and the coffee kitchen associated with it. These spaces are only occupied in a very transient way as people tend to use them on the way to elsewhere. People from the entire department, not just the MRL, frequent them. Here, there is certainly no defined ownership and control apart from that exercised on an institutional level.

**Physical home cells**

At different times, researchers choose to work from home. A home space would be a private space, not only occupied by members of staff but possibly members of their family as well, at least at times. Here shared control, ownership and use of an MRACell could be studied in a private setting.

In the end three of these types were implemented: single office, shared office and meeting room. A description of where these were set up for the main study can be found in sections 7.2.1, 7.3.1 and 7.4. The set-up process is described in more detail in section 7.4.1.

## ***6.6 Participant representation***

In contrast to the pilot study and indeed most other applications of virtual reality, inhabitants of MRA are only represented by themselves. In physical space this is through their own bodies, while in virtual space they are represented through the video image of their own bodies. This fulfils most but not all criteria

for good CVE embodiment design as suggested by Benford et al (Benford, et al, 1995). The video view of inhabitants embedded in a virtual environment can show the presence of inhabitants and their location, identity, activity and orientation to physical and virtual content. The representation is truthful in the sense that it depicts people as they are and does not generally allow any changes like avatars would. Gestures, body language and facial expression are all represented to varying degrees, depending on the video quality available in any particular implementation. Video might also be used to show the history of somebody's activity and could be transformed according to observers' needs or computing restraints. Although the introduction of avatars in addition to the video already available was considered initially, especially to give access to MRA to individuals without an MRB, it was later discounted as it would have overcomplicated matters, especially in terms of the interface required to control such an implementation but also in terms of issues that arise when multiple representations are in use (Koleva, et al, 2000). In addition to the above, rooms are of course specifically represented within MRA as MRACells. So what usually would be a person's avatar has now become their office's avatar with a very similar functionality.

## ***6.7 Representation of the MRA***

The topology of MRA is designed to be publicly available. Boundaries and links can be seen and used by anyone who is present in the relevant spaces. However, people not currently using MRA or without the appropriate technology to connect to it, might still have a genuine interest in what events are taking place within MRA.

These events could be represented externally to the system in form of a virtual map or even physically when physical spaces that are virtually close to each other within MRA are linked for example with light effects in physical space such as projected lines. The usefulness of such a representation for the understanding of the topology of MRA and for actually meeting up with inhabitants of MRA could be studied. However, this idea was discarded as it was impractical, especially the representation of MRLinks in physical space, since the connected spaces were physically too far apart. Instead a live map of MRA was implemented as part of the interface itself as has already been mentioned.

## ***6.8 A dynamic spatial interface***

This chapter has detailed the main design considerations and decisions relevant for the second major phase in the prototyping process. This has led to the introduction of the concept of the MRACell as a combination of one physical and one virtual cell. The function of MRACells as dynamic tools to establish social interaction between remote physical spaces and their influence on the overall topology of MRA has been outlined. Following this, appropriate physical locations and the representations of inhabitants as well as of the overall MRA were discussed. MRACells are designed to represent architectural spaces and their dynamic adjustment across virtual space allows inhabitants to change the architectural topology around them according to their requirements. Although based on the experience with the earlier prototype and guided by relevant related work in the area, the above concept still presented a number of novel ideas that had not been explored previously. The following chapters chart the exploration of these ideas in detail.



# 7

## Study 2: Mixed Reality Architecture Prototyping

The construction of MRA began with two prototyping phases. The first phase was an initial pilot study with three MRACells, conducted during October 2003. The second phase was a follow up study with four MRACells, conducted between January and June 2004. These two phases of the development took place within the day-to-day activities of the MRL, a working and very active research environment.

The overall aim of the evaluation of the two prototypes was to better understand issues in the design, construction and use of MRA, and this required an evaluation of the suitability of the implementations and the concepts that led to its design but also the uncovering of additional unforeseen issues. These earlier findings were then fed back into the development cycle, with the goal of produc-

ing a robust and useable implementation that could be evaluated longer term with local MRACells but also at other sites. The following outlines an initial survey aimed at gaining a better understanding of the existing social interaction, before detailing the first two phases in the prototyping cycle.

### ***7.1 The existing social networks***

The overall setting for the study of MRA has already been described in section 4.1.1 in terms of its spatial distribution, organisational changes and population. For a better understanding of social interaction and its relation to space in the environments concerned, an interview survey was conducted. The aim was to establish a base line description of certain aspects of the existing social network and social interaction in the respective organisations. The analysis of social networks within organisations has become increasingly popular, because of the recognition that their constitution has a major influence on how work actually gets done (Cross, et al, 2002). It has also been shown previously how much physical proximity directly impacts on collaboration (Kraut, et al, 1988). In the context of this research, the standard method to investigate social networks as for example employed by Penn et al could not have been used (Penn, et al, 1999), as it entails the use of a questionnaire that lists everyone in an organisation, which respondents can then select from. The focus was on investigating local and remote social relationships and listing everyone possibly belonging to the respondent's social group was simply unfeasible, because this group was unknown to the author. Therefore respondents were asked to list the members of their social networks themselves.

Because MRACells were set up in a staggered way, the interviews were conducted over a longer time period, but always before the installation in the space occupied by the people to be questioned. The interview consisted of two parts. The first part was concerned with existing informal social interaction within the work environments of participants, while the second part investigated social interactions that were not currently taking place, but were deemed desirable for work by participants. What follows is a detailed description of the results of the interview survey. Its schedule can be found in appendix 11.2.

Overall 19 people were interviewed. Ten people participated from the MRL in Nottingham, eight people participated from the VRCentre, UCL and one person participated from VECG group, UCL. During the time the study was running, a number of people moved into and out of spaces where the MRACells had been set up. In addition, one person, who was also later a very active inhabitant of MRA, moved offices repeatedly during the study. Before the set-up was established in her office, she moved from the second floor of the MRL to the ground floor, where an MRACell was then installed. Through a change of jobs she then moved to Bath University where she first occupied an office in a building separate from her department, before moving into another, larger office in the main building. The MRACell first installed in Nottingham was taken along and installed in both the Bath offices (more details can be found in sections 7.3.1 and 7.4).

In total 175 people were listed and then categorised by the 19 participants as being encountered informally at work, and 90 people were listed and categorised as being informally encountered too infrequently. The descriptive categories were then concerned with the relative spatial location of these people, the working relationship with them and the type and quality of the existing social interaction.

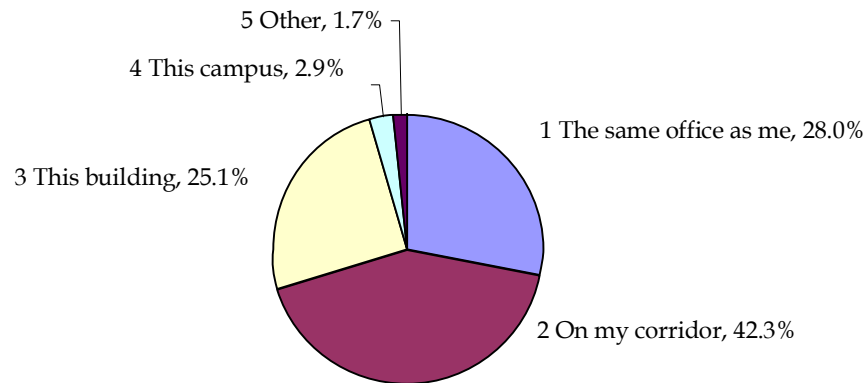
### **7.1.1 Existing informal encounters**

As a first step, participants in the survey were asked about their informal encounters at work. The question was: *Could you please list the people who you regularly encounter outside arranged meetings or informally at work? Please do this for a typical day during the last month and list 10 people.* It was made clear to participants that the identity of the people listed was not part of the study and that they could list placeholders, if they wanted to. Participants listed between 5 and 10 people. 175 people were listed overall.

#### **7.1.1.a Spatial location**

Participants were then asked to categorise who they had just listed. The instruction was: *Could you please categorise the people you listed according to the following categories. Please provide additional details in the space provided, if necessary.* The first category dealt with the relative spatial location of the people listed. The question

was: *Where are they based?* Five categories were provided as shown in the graph below.

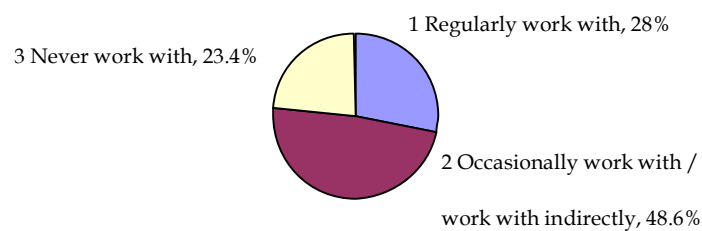


**Graph 1 Where are they based?**

As could probably be expected, only a very small proportion of 4.6% of the people regularly encountered was based outside the respective buildings of the 19 participants. Over 70% were physically very close by, in the same office or on the same corridor and a further 25% were located within the same building.

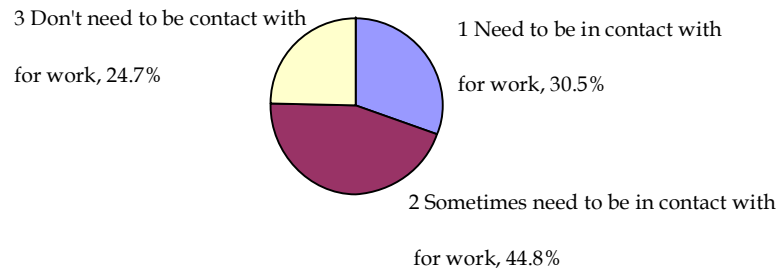
#### **7.1.1.b Working relationship**

The two following questions were included to assemble a description of the working relationship that people had with others who were regularly encountered. The first question was: *What is your working relationship with them?* Three categories were provided as shown in the graph below.



**Graph 2 What is your working relationship with them?**

The second question was: *What are your contact requirements?* Again, three categories were provided as can be seen in the graph below.



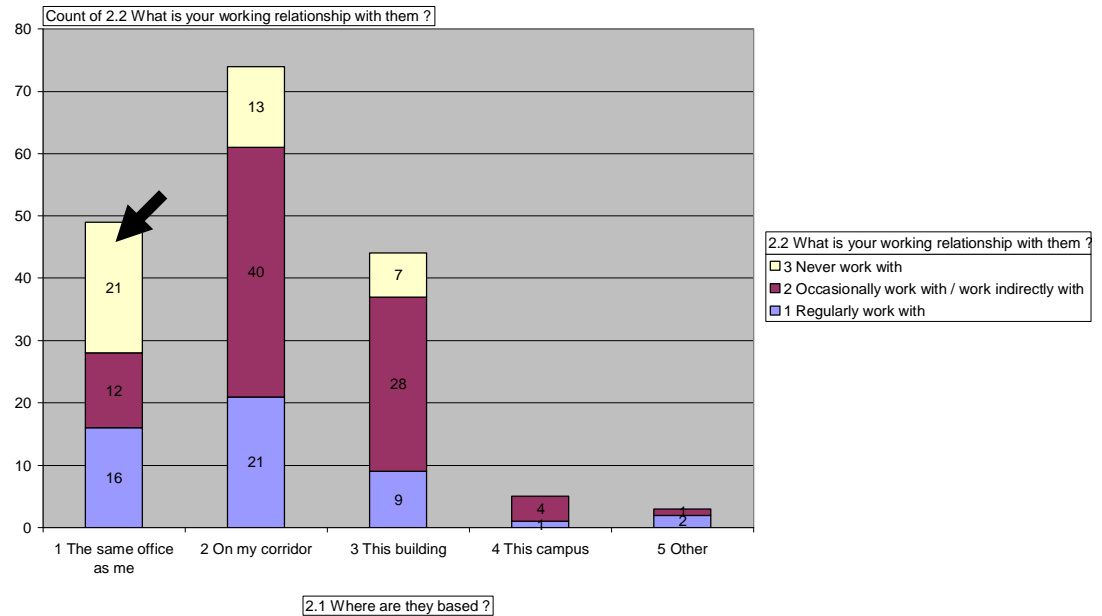
**Graph 3 What are your contact requirements?**

What is shown here is that only a proportion of around 30% of the people informally encountered by participants were categorised as being worked with regularly or being important to have contact with for work. At the same time, the 19 participants stated that they never worked with or did not need to be in contact with over 20% of the people regularly encountered. The remainder, just under half of all people listed, fell into the second category: they were occasionally worked with, indirectly worked with or needed to be in contact with only sometimes.

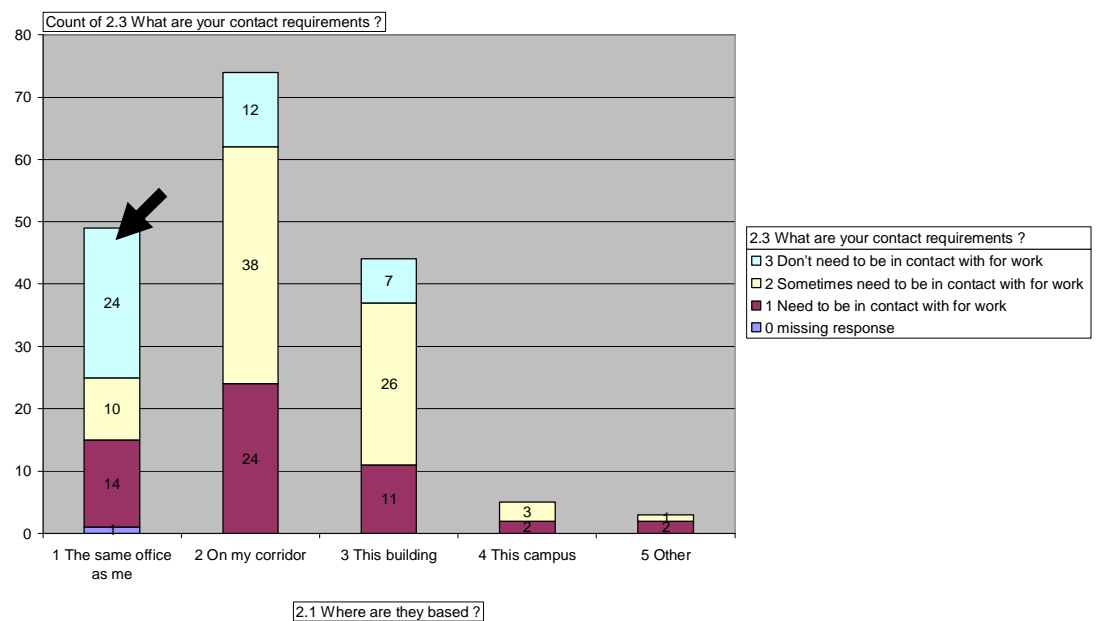
In summary, the data shows something very much to be expected. In the type of environment under investigation, relatively large research institutions with many activities taking place at the same time, people encountered during a working day are not necessarily the people that one is involved with very closely for work. However, there is still considerable overlap. The collected data also allows a more detailed analysis of spatial proximity in relation to working relationships and working requirements. This is shown in the following two graphs.

Graph 4 plots the relative location of people against the working relationship that participants said they had with these same people. What is most notable here is that a considerable proportion (21/49 or 42%) of people listed as being in the same office as the person asked, are described as never being worked with.

This can also be shown with Graph 5 that plots the relative location of people against the contact requirements that participants stated that they had for them. The result is very similar to the previous graph in that a considerable proportion (24/48 or 50%) of people who are located in the same office with respondents are rated in category three. People expressed the fact that they did not feel that they needed to be in contact with those people for work purposes.



**Graph 4 Spatial relationship - Working Relationship**



**Graph 5 Spatial Relationship - Contact Requirements**

Another observation that can be made from the data concerns the other end of the graph. None of the people described as being outside the participants' building and/or outside the participant's campus were placed in categories three: *Never work with* and *Don't need to be in contact with for work*. From this correlation one might be tempted to argue that relative physical distance does not necessarily translate into less collaboration or a smaller need for contact. However, as

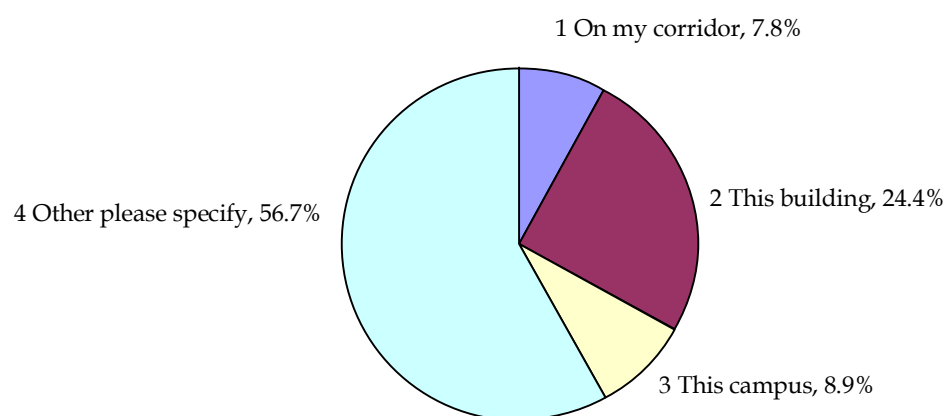
these people were physically encountered at the respondents' sites, they must have travelled there for a reason, which was most likely related to work matters. Even if they did not come to see one of the respondents to this survey but travelled to see somebody entirely different, it seems that the people who did travel to the respondent's physical site were generally regarded as 'useful' by respondents.

### 7.1.2 Desired social interaction

The final part of the survey was designed to identify informal encounters that people themselves would classify as being beneficial for their work. The question was: *Could you please also list the people you could see a benefit being in contact with for work but do not meet informally or not as often as you would want. These people do not have to be from this site.* As before it was made clear to participants that the identity of the listed people was not part of the study and they could list placeholders, if they wanted to. Participants listed between 0 and 10 people. 90 people were listed overall.

#### 7.1.2.a Spatial location

Participants were then asked to categorise the people who they had just listed. The instruction was: *Could you please categorise the people mentioned according to the following categories.* The first category dealt with the relative spatial location of the people listed. The question was: *Where are they based?* Four categories were provided as shown in the graph below.

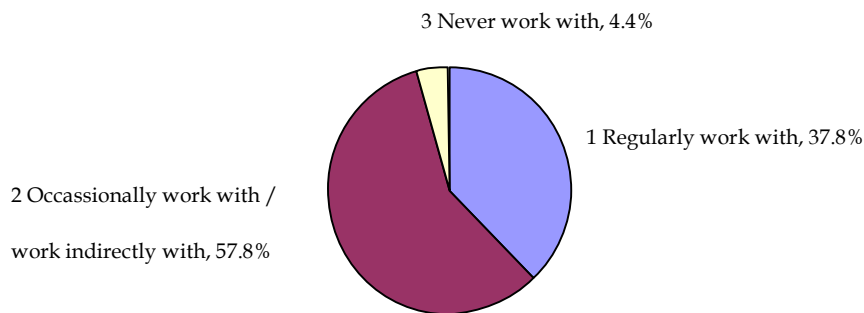


Graph 6 Where are they based?

Over 55% of the people listed were described as being located outside the same campus as the person who had been asked. Participants were also asked to provide further details about the locations of people place in category 4. The answers were coded. Of the people categorised, 35% were listed as being from a different campus of the same organisation, 19% as being in the same city, 23% were listed as being from a different city, 17% were listed as being located in a different country and 6% were listed as having a location unknown to the participant, the last categorisation being a notable finding in itself, although not necessarily unexpected for a research environment.

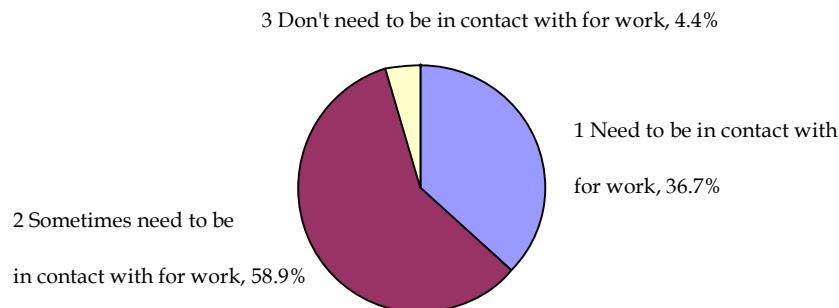
### 7.1.2.b Working relationship

The two following questions were then designed to gather a description of the working relationship that people had with the people listed above. The first question was: *What is your working relationship with them?* Three categories were provided as can be seen in the graph below.



**Graph 7 Working relationship**

The second question was: *What are your contact requirements?* Again, three categories were provided as can be seen in the graph below.

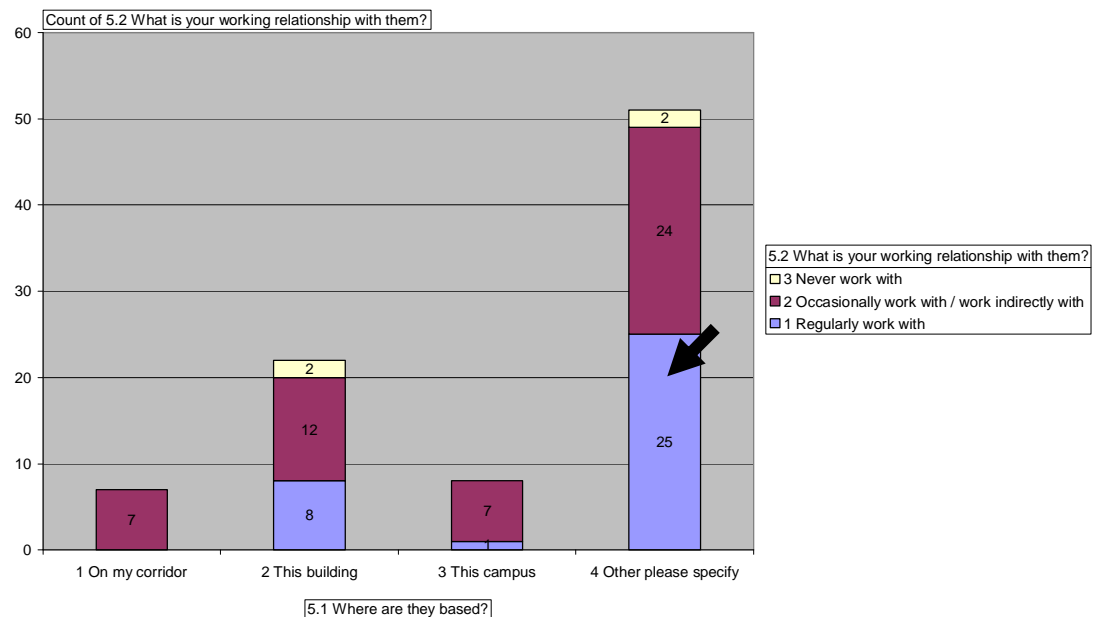


**Graph 8 Contact requirements**



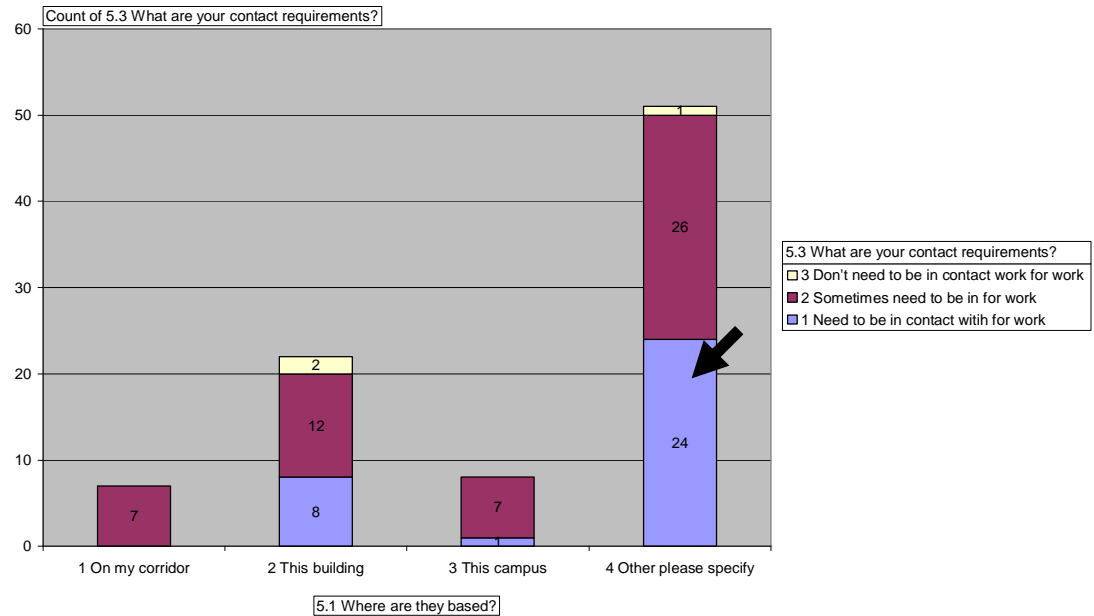
The two graphs above show that over 35% of the people listed as not being met informally or not as often as respondents wanted, were regular work partners or people who respondents stated that they needed to be in contact with for work. The majority of people, just under 60%, were placed in the respective second categories: *Occasionally work with / work indirectly with* and *Sometimes need to be in contact with for work*. Only a very small proportion was listed in the third category. In summary, the data shows that there is a considerable proportion of work colleagues to whom participants felt that they do not have sufficient informal access. They might not meet them often enough in general or might have to arrange formal meetings to make contact.

Again, the collected data allows a more detailed analysis of spatial proximity and working relationships and working requirements. This is shown in the following two graphs. Graph 9 plots the relative location of people against the working relationship that participants said they had with these same people.



**Graph 9 Spatial Relationship - Working Relationship**

The results reflect what has been found about working relationships with people located close to each other. In total, 51 people were listed as being located away from the campus of the respective respondents. Just under 50% of these people were then described as regular work partners.



**Graph 10 Spatial Relationship - Contact Requirements**

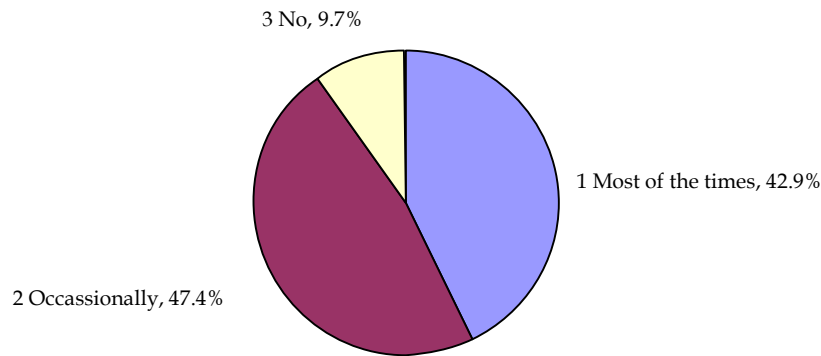
Graph 10 paints a similar picture. Nearly 50% of the people listed as being located remotely are placed in category one: *Need to be in contact with for work*. The results clearly show that in this environment, a sizeable proportion of work colleagues were physically not co-located with respondents.

Another notable feature of the data is that of the people placed into categories 1 (*Regularly work with/Need to be in contact with for work*) eight (more than 35%) were actually located in the same building as the respective respondent. An attempt was made to find an explanation for this in the working relationship between respondents and the people they listed, but the data is too limited to give more than an indication. In four instances, the person listed was a professor and in two instances the person was a PhD student of the person making the listing; both groups of people in high demand to the other, for entirely different reasons, naturally.

### 7.1.3 Type of encounters

As already mentioned, additional data was collected on the types and quality of informal encounters that people were experiencing. Participants were given the following general instruction: *Could you please describe the types of encounter you had with the people you listed. Please provide additional details in the space provided, if*

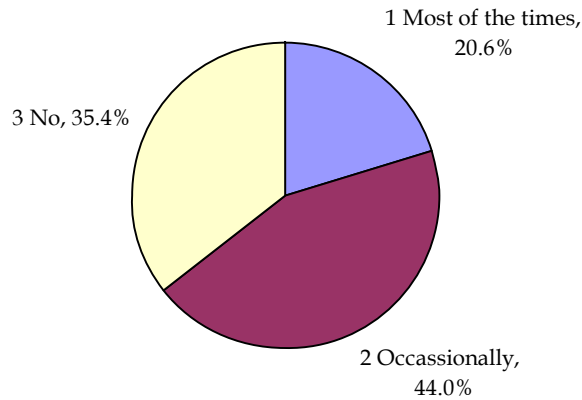
necessary. The first direct question was: *Did the above encounters typically lead to conversations whether work related or not?*



**Graph 11 Did the above encounters typically lead to conversations whether work related or not?**

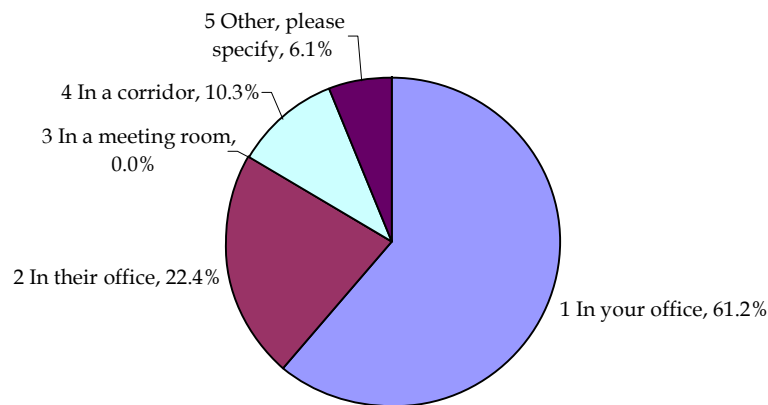
Participants stated that just over 40% of the encounters listed did lead to conversations most of the time, more than 45% led to conversations occasionally, while only about 10% of encounters did not lead to conversations. To provide more details, participants were also asked the following question: *For encounters that did lead to conversations what was their subject?* Of the conversation listed, 50% were concerned with work as well as non-work related issues, about a third were concerned with work related issues only and a sixth were concerned exclusively with non-work related issues.

A further pair of questions concerned the possible exchange of documents during informal encounters. Participants were asked the following question: *Did encounters lead to an exchange of documents or objects whether electronic or physical?* The graph below illustrates the results. For just over 20% of the informal encounters, participants stated that documents were exchanged most of the time, for 44% of the encounters, documents were exchanged occasionally, while just over 35% of encounters were described as not resulting in an exchange of documents. To provide more details, participants were also asked the following question: *For encounters where documents were exchanged what was the type of those documents or objects?* Of the documents exchanged, nearly 33% were electronic and only 10% were physical. In just over 55% of cases, electronic as well as physical documents were typically exchanged.



**Graph 12 Did encounters lead to an exchange of documents or objects (electronic or physical)?**

The final set of questions was concerned with the location of the encounters. Participants were asked the following question: *Typically where did the encounters take place?*



**Graph 13 Typically where did the encounters take place?**

A large proportion of encounters, just over 60% took place in the office of the respondent. This reflects the fact of the large proportion of people being physically close to the respective participants as can be seen in Graph 1. About 22% of encounters took place in the other person's office and a further 10% on a corridor. For this question a considerable number of participants offered multiple responses. However, only the first one mentioned is included here. The final question concerned the appropriateness of the location of these encounters: *Was the location of the encounter appropriate for the subject of the conversation?* Over 90% percent of respondents indicated that they considered the location of the informal encounter appropriate for the subject of the conversation.

#### 7.1.4 Summary

What this data can show is that the environments that were under investigation here are ideal test beds for the prototyping process of MRA. A high proportion of co-located people are not direct work colleagues and a high proportion of people with whom more informal social contact is sought with are physically remote. Additionally, a high proportion of existing informal encounters led to social interaction, whether work-related or not and only a small proportion of document exchanges were physical. MRA is designed to support informal and also more formal remote social interaction and the study of how it can do this is the subject of the following sections.

### 7.2 *Prototyping Phase 1*

During the initial prototyping period of around three weeks, which took place during October 2003, three MRACells were set up and their use was explored. The immediate aim was to identify and deal with technical issues in the design and implementation of MRA as constructed for this prototype, to be able to rectify any problems before widening the base of inhabitants to people outside the research groups. From these findings necessary changes to the MRA itself but also the details of the method of evaluation were then derived. In addition, focussing much more on the use of MRA, the goal was to start recording and describing the types of events that can be observed within MRA and to investigate in what circumstances MRA would be suitable to deploy.

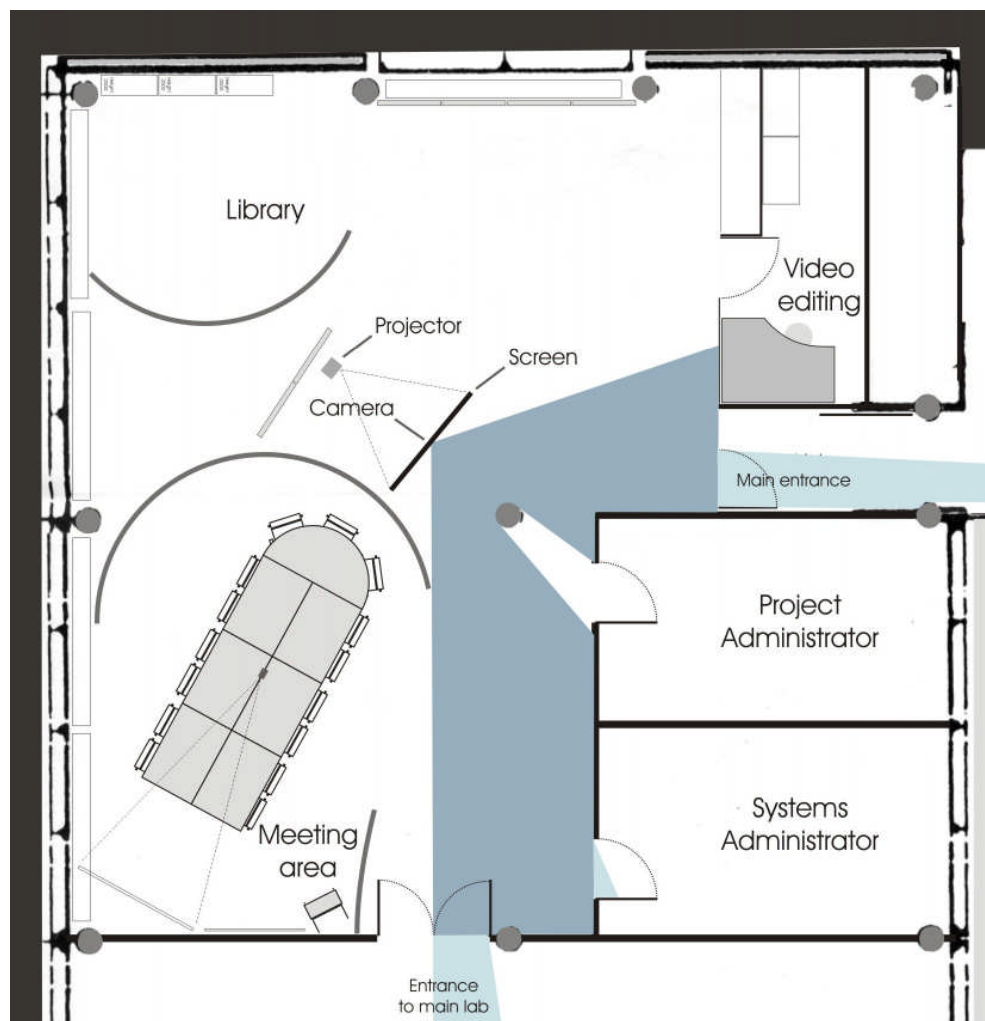
During phase 1, the underlying MRA system (MASSIVE3 environment) was running for approximately 270 hours in total, of which 77 were during the typical office hours of the MRL. Realistically, only at that time was any interaction to be expected. It is worth noting that this took place within a typical office setting and therefore the MRA system had to fit around the everyday activities of the research lab.

#### 7.2.1 MRACells during phase 1

The following is a brief description of the three MRACells set up for the prototype study (for the design of MRACells and MRA overall see chapter 6). Issues that were relevant for the installation of all MRACells are also reflected on.

### **MRL meeting room and foyer, MRL, Nottingham**

This is the main meeting room of the MRL located on the first floor of the north wing of the building. It acts as the main access to the laboratory area and some offices beyond. The plan below illustrates its layout. The black area around the top is the exterior and the grey area in the bottom right corner is a covered atrium. Projector, screen and camera are labelled near the centre of the figure. The MRA camera's field of view is marked in blue, with areas that could potentially be seen marked in lighter blue. Those are zones of the field of view that could be seen, if doors were open for example. This same representation scheme will be used for all following plans included as parts of the description of the different MRACells. Weekly seminars take place here. The room holds the local MRL library and facilities for video editing. The office of the project administrator of the largest MRL project is adjacent as is the office of the local system administrator.



**Figure 29 MRL foyer - plan**

It is a space that often leads to chance encounters between people during a normal working day. Figure 30 and Figure 31 below show the view from the MRA camera and a view of the screen from the main entrance respectively.



**Figure 30 View from MRA camera in the MRL foyer**



**Figure 31 MRACell in MRL meeting room and foyer**

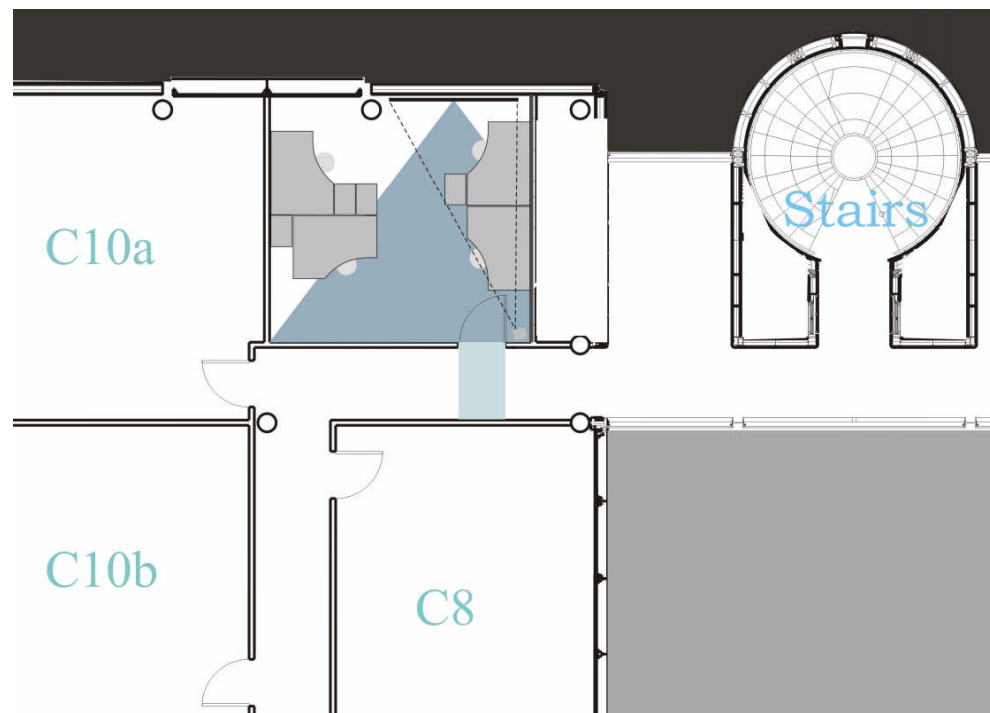
In summary, the MRL meeting room can be described as central to the MRL as a whole; certainly central for and to the MRL researchers located on this campus of the University. Most people working in the MRL pass through this space at least once per working day. At the same time, the amount of time spent in this space is relatively short apart from occasions when a meeting is taking place.

The MRL meeting room is publicly owned and controlled in the sense that it does not 'belong' to any one researcher in the lab in particular and it seemed likely that no person in particular would take responsibility for it. As a result of the above the MRACell was designed to be immobile in virtual space to provide a focus and 'home' for MRA content. Its virtual side was also scaled up to make it

appear more significant and it was located in such a way that MRACells entering would face it in virtual space. There was also no interface to its privacy controls to stop people leaving it in a state that would stop the other two cells communicating with the space.

### **C9, MRL, Nottingham**

Room C9 is a shared office on the second floor of the north wing of the building. The author originally shared this office with the part-time MRL secretary Anne. During the course of the study, the occupancy has changed a number of time with Xenia and Gemma moving in and then Anne and Xenia moving out. It is located on a relatively busy but not central corridor leading to some other offices and seminar rooms. MRL researchers and students pass by every day resulting in a general awareness of each other. Occasionally, researchers entered to discuss administrative matters with Anne and when she was located there, Xenia. The following graphic illustrates the layout of C9. For an explanation of the symbols refer to the MRL foyer section.



**Figure 32 C9 - Plan**

The ownership of and control over C9 is shared. Its location leads to a limited number of chance encounters between its inhabitants and people passing by on their way to their offices. Therefore, it has been represented in the MRA virtual space with a mobile MRACell having shared control over its privacy settings.



Figure 33 and Figure 34 show the view from the MRA camera in C9 and a view of the screen respectively.



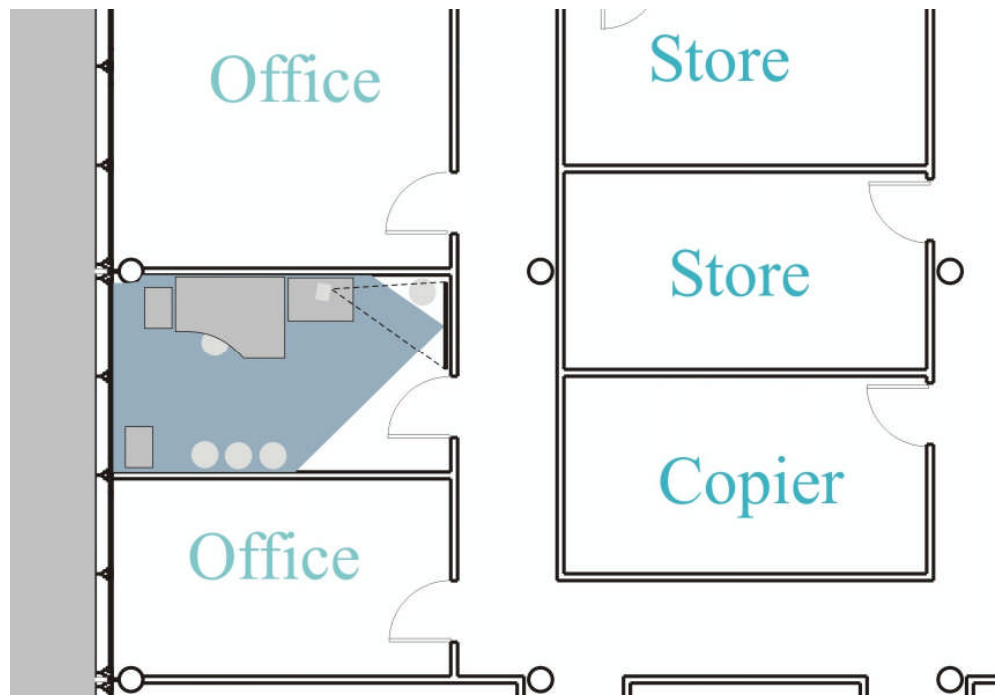
Figure 33 View from MRA camera in C9



Figure 34 MRACell in room C9

### **C54, MRL, Nottingham**

Room C54 is a single office located on the second floor of the middle wing of the building. Kate, a lecturer in the department and the main collaborator on the pilot study, occupies it. It is located on a relatively busy central corridor linking the vertical circulation of the building with the main administration area of the Computer Science department. Students enter C54 regularly for small group meetings and tutorials. However it is relatively far away from other part of the MRL: offices and the lab itself. Figure 35 below illustrates its layout.



**Figure 35 C54 - Plan**

Figure 36 and Figure 37 show the view from the MRA camera in C54 and the view of the MRA screen, respectively.



**Figure 36 View from MRA camera in C54**

Ownership of and control over this space are with Kate alone. Its location leads to a limited number of chance encounters between its inhabitant and people passing by on their way to the administrative area or their offices. Therefore, it has been represented in the MRA virtual space with a mobile MRACell that has individual control over its privacy settings.



**Figure 37 MRACell in C54**

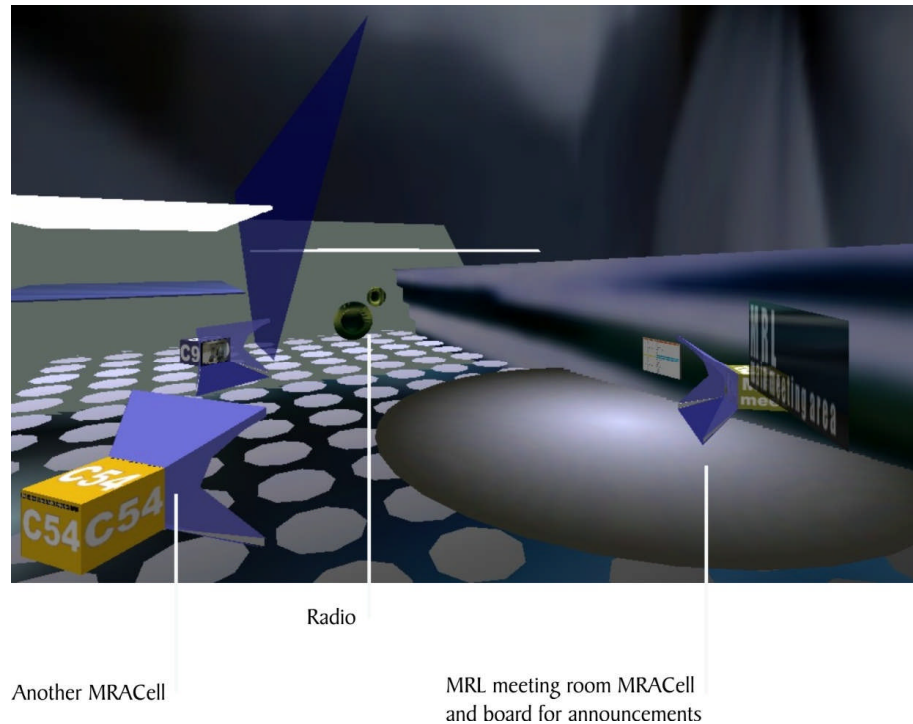
### **Summary**

These three spaces are very different in their use. There is one public space that is available to a great number of people in the Mixed Reality Lab and two much more private offices. These are private in terms of their more restricted occupancy and the issues of ownership and control associated with this but also in terms of the types of meetings that regularly take place in these spaces. The three spaces are distributed across two floors over two wings. They are not adjacent but local in the sense that they can be reached via the circulation system within the Computer Science building. They provided a good starting point for the analysis of MRA.

The cells can be described as being linked by or embedded within physical public space. This would for example be through adjacent corridors or open space outdoors. This introduces a topology that consists of private and public areas that inhabitants need to traverse physically to get from one space to the other. There are rules in place according to which people are granted or refused access and these rules are typically enforced by physical boundaries between private and public but also by invisible rules such as customs. For example it is generally not accepted for a person to linger next to an office door out of sight of its occupants for too long. This would most likely be seen as attempting to eavesdrop on conversations.

As each one of these spaces is the physical part of an MRACell and has the interface technology to 'display' MRA set up within it, it can also be described as being linked by or embedded within virtual public space. For this study the public virtual space linked to was the same for all MRACells (see Figure 38). It was

designed to be large enough for all connected MRACells so that different groups might be formed at the same time. Just like the surrounding physical space, the surrounding virtual space can be seen as more public than the embedded physical cells. It was therefore desirable to control access to the more private physical cells from public virtual space. This was achieved with measures introduced as part of the overall design of MRACells (see section 6.3.2)

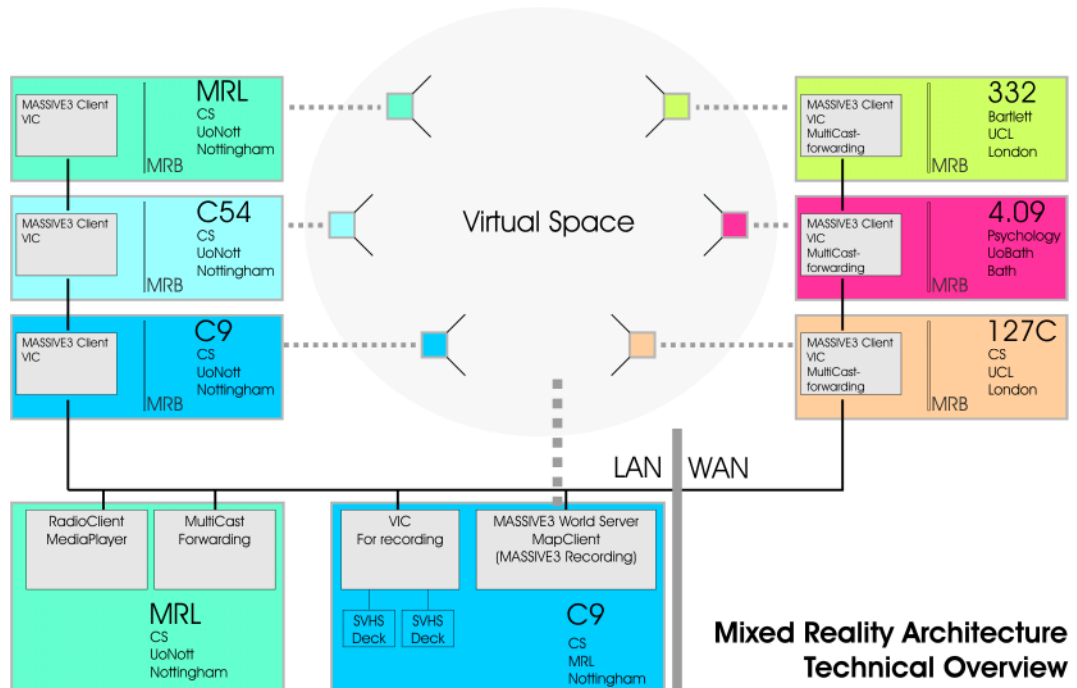


**Figure 38 MRA: Overview of virtual space**

### 7.2.2 Technology

In the following sections the technological set-up for the study of MRA is outlined. For simplicity, only the final state of the implementation is considered here, when six MRACells were connected together. Chapter 7 provides separate descriptions of the two additional development stages that will make clear what was implemented at what stage. Figure 39 below shows 6 MRACells connecting into the same virtual space depicted in the middle of the graphic. Those cells comprised 6 separate physical spaces, labelled MRLM, C54, C9, 332, 4.09 and 127C, which are the numbers of the respective rooms. MRA ran on standard Windows PCs, first using Windows2000 and then WindowsXP. This required 10 networked PCs, which are labelled PC1 – PC10.

PC7 ran the MASSIVE3 environment as a server, keeping track of events in the virtual environment and synchronising these with the client PCs. It also ran one of the clients itself, which generated the overall map of the environment. This map view was output over the graphics card and then re-captured by the built-in video capture card to be able to stream it using VIC, a video conferencing application freely available from UCL.



**Figure 39 MRA Technology**

Additionally, PC7 ran the MASSIVE3 Record&Replay application at certain times to collect material for analysis. Record&Replay allows the recording and later replay from different perspectives of events as seen by the MASSIVE3 environment (see section 4.2.5). PC 6 ran an instance of the VIC application to collect video broadcast from the different MRACells and the map view generated by PC7. These views were arranged on two monitors, output via the graphics cards, converted via scan converters and then recorded on to S-VHS tape.

In addition to these two machines, two additional machines were required for the infrastructure of MRA. Because some of the external sites blocked multicast traffic (the protocol used by VIC), the video traffic had to be tunnelled between the four connected Local Area Networks (LAN), for which PC5 was set up at the Nottingham end. The remote machines, PCs 8-10, ran an associated tunnelling process. Finally, PC4 ran an additional MASSIVE3 client providing streamed music from various sources. This was only added to the MRA at certain times,

usually at the end of the day, so as not to strain bandwidth requirements too much.

The other six machines, PCs 1-3 and PCs 8-10 all ran a MASSIVE3 client providing the respective views into the MRA using one MRB per MRACell . This view was projected on to a large surface (wall or projection screen). Audio generated within the MRA by other clients or the radio was emitted through speakers connected to the PCs' audio cards. The camera/microphone combinations associated with each of the MRACells were then used to capture live video and audio to make it available within the MRA. VIC was used to capture the video and broadcast it as an RTP stream. All of the client machines also ran RADMIN, a commercial application, allowing the remote administration of the installation of software and the running of the clients.

### 7.2.3 Introduction to inhabitants

Once the technology was set up in the spaces described above, inhabitants were given a brief introduction to the interface to MASSIVE3, if they had no experience with it already. A mouse was used for navigation on the ground plane and the keyboard for flying up and down and for changing the privacy settings from open to semi-private to closed. The introduction also included a general overview of the on-screen interface (see Figure 40).

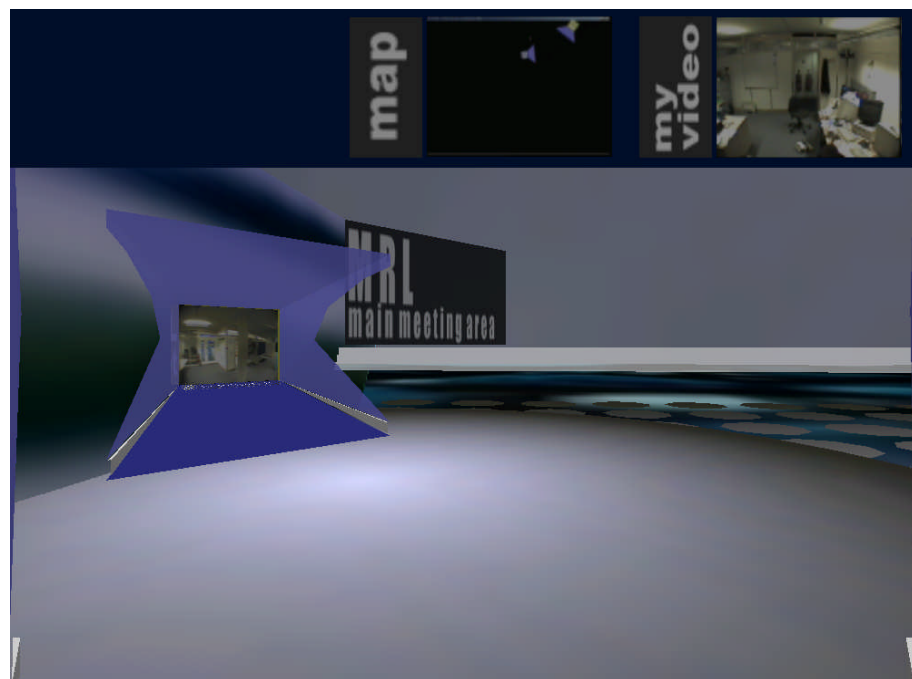


Figure 40 MRACell view from physical space as projected in all three offices



There are a number of features to this interface. A map at the centre of the top of the screen displays the entire environment and all its currently connected inhabitants. The video to the right of the map allows people to see whether they are in camera view and how close they might have to move to the camera to be seen properly by others, while the main part of the interface displays a first person view into the virtual space of the MRA. Communication with another inhabitant then entails using the mouse to move one's own MRACell close to one or multiple other cells, so that the video is clear enough and the audio levels suitable. Then it is a matter of attracting somebody's attention usually via the open microphone, waving into the camera or by virtual movements.

#### **7.2.4 Changes to the system during prototyping**

A number of changes were made to the system during the prototyping process. The aim was to iron out small problems but also to adapt the system to the local situation. What follows is an overview of these changes. Some modifications to the general lighting were attempted with the aim of providing a clearer view of remote spaces. This was discarded as an increase in the local lighting level adversely affected the visibility of the projected image. The background of one of the video views was slightly 'decluttered' with the same aim, while it was recognised that in practice designers of MRA would have very little influence on such details if the system were to be expanded to other sites.

The video frame rate was increased to about ten frames a second. Here it was necessary to balance the bandwidth requirements of the video, at this point uncompressed, with the interaction requirements. To improve the audio quality, prevent feedback and reduce the echo across the network, physical speaker position and the PC audio settings were tweaked. Additionally, the Massive3 audio nimbus was adapted (Benford and Fahlén, 1993). The audio nimbus of a participant adapts the audio awareness that others have of this participant. The changes to the audio nimbus were aimed at allowing a suitable visual access to other MRACells while at the same time not flooding them with background noise. There were also changes to the size, clarity and update rate of the MRA map to improve its readability.

As already mentioned the virtual sides of the MRACells were initially designed at different scales. The MRL meeting room appeared twice the size of the other

two cells. Consequently, users of the two smaller cells (C9 and C54) tended to remain at a relatively large distance away from the larger cell (MRL meeting room) since to them, the latter appeared at a suitable scale. In contrast, for users of the MRACell at the MRL meeting room this meant not being able to see properly into the other offices, as they appeared to be too far away. This was compounded by the fact that there was no navigation available at the MRACell in the meeting room so users were not able to rectify any problems they might have had. At this particular stage of the trials it was also already noted that the meeting room MRACell was being used far less frequently than both the two office cells. Therefore, it was felt that the increased scale was not really warranted and the scales were changed to be equal for all MRACells.

### **7.2.5 Evaluation**

The main method of evaluation during this phase of prototyping was an observational study (see section 4.2.2) using remote video recording. This was done with a single MiniDV camcorder located in the author's office. This was connected to an additional computer, which was used to assemble the views taken from the three MRACells and output them via S-Video. Three sessions of 90 minutes each were recorded (video and audio) and analysed. Times of recording were always announced to the people directly involved. The video material consisted of the video feeds streamed from the MRACells and as seen by the system. They represented the types of events that took place on the physical sides of the different MRACells, as visible from the respective cameras mounted there. At the same time a top down view of the entire MRA was recorded to capture the configurations emerging from the MRA. This map represented well what the configurations were like although it cannot show what individual participants would have seen from their respective virtual viewpoints. However, combining the video and map recordings does allow a good analysis of this.





**Figure 41 Panel of material recorded (retouched for clarity)**

Figure 41 shows the videos of C9, the MRL meeting room and C54 from (the introduction of these spaces follows below) from left to right respectively. The MRA map is located at the bottom right. This represents the MRA in its early prototyping stage. The above method of evaluation was complemented by generally keeping in touch with participants to clarify events recorded on video but also by collecting additional comments.

## **7.2.6 Observations**

The video data recorded provided a number of early insights into the performance and usability of the system. Different types of events taking place within the MRA were recorded. Those can be differentiated into two broad types: events located in physical space with seemingly no impact on interaction within virtual space and events taking place across the MRA. The following is an overview of these events with concrete examples for illustration.

### **7.2.6.a Events in physical space**

**People just walking past the MRL meeting room MRACell.** There were many instances where people just walked past the MRL meeting room boundary. Often people glanced at the screen but did not interact. Some participants did state however that it was still useful for general awareness of others even without verbal interaction.

**Conversations off camera.** There were occasions when conversations took place, for example in the meeting room, outside the view of the camera placed there. It is likely that this was not noticed by people. Their conversation would have been audible (but not understandable) for people virtually close to that particular cell, which could have caused problems in terms of privacy in some cases.

**Changes in physical location interfering with the system.** Kate in C54 at one point turned the amplifier and projector off, which could not be seen by others in the MRA. The MRACell was also set to 'private', which would have been visible. The 'private' state does not affect audio, and sound communication should have been possible. Only a phone call allowed the situation to be rectified. Another example was when the physical boundary in the meeting room was taken down for changes to the set-up. Although the MRACell was also set to 'private', it would have appeared 'audio-available' to others. In fact it was completely unavailable during the set-up period.

**Physical meetings that were not related to MRA.** These meetings took place in physical space in the background. If inhabitants did not take measures to increase the virtual distance between them this did have a distracting effect (see below). A number of occasions were recorded where multiple meetings were taking place at the same time in different physical spaces. Usually, participants did increase the virtual distance between each other to a suitable level to avoid distractions due to audio being broadcast.

#### **7.2.6.b Events across MRA**

**Greetings across the MRA.** These usually took the form of simple acknowledgments, like 'Good morning', when people saw each other for the first time on any given day. Often it was simply a short waving of hands, quite visible across the video.

**General small talk across MRA.** The author and Kate used MRA for chatting about events that had happened around the office earlier. These events were preceded by appropriate repositioning of the MRACells for audio and visual clarity.

**Arranging of physical meetings across the MRA.** For example, the window in C54 blew open as a result of a gust of wind. Kate moved virtually closer to C9

and asked for help with shutting it again after trying herself without success. This resulted in a physical meeting in C54.

**Moving position to attenuate audio levels.** Virtual repositioning was frequently used to attenuate audio levels. Sometimes this was aimed at not disturbing others. One example was when Kate had arranged a tutorial with a student in B54. Just before they started the tutorial, Kate navigated the MRACell out of the way to a 'quieter' area of the space and turned it around. She did not set the boundary to semi-private or private, but virtual distance was being used so as not to be disturbed by others. At other times this was done as a pre-emptive measure when it was clear that one didn't want to be disturbed. For example, this was the case with meetings taking place in the physical MRL meeting room.

#### **7.2.6.c General observations**

There were a number of other more general observations that are worth mentioning.

**Slowness of interface.** As already mentioned, virtual distance was designed to attenuate the audio levels between MRACells. However, in comparison to lowering the audio level on an amplifier for example this proved to be quite slow. The use of mouse and keyboard for interaction appeared to be too clumsy and got in the way of other activities (e.g. picking up the phone). Especially for brief meetings that were taking place in physical space the associated MRACell often remained in position, potentially causing problems through the audio being streamed. Another reason for this might be (as one inhabitant noted) that relocations to quieter positions and the movement back into the public arena had simply been forgotten.

This prompted consideration of a number of changes. Pre-scripted positions for the MRACells might reduce the cost of moving them. Alternatively, their location might be semi-automated depending on for example whether the cell was occupied or not. However, in the end it was decided to opt for a different interface to MRA as will be described below.

**Privacy settings.** The intention was that people would use the different privacy settings to indicate their availability to others. This would entail setting the semi-transparent state when they did not want to be disturbed while in the physical

part of their MRACell, and setting the opaque state when they had left. This seemed hard to remember to do. There were many instances where the virtual part of the MRACell was left open when the physical part of the cell was unoccupied.

Again, one possibility might have been to semi-automate this feature depending on whether a particular space was occupied or not. On the other hand this might have been a feature that inhabitants simply did not find useful or needed time to get used to.

**Location of events.** Events in remote physical space did sometimes appear as if they had happened in local physical space. When a person knocked on C54's door, Anne in C9 was prompted to look around to say 'hello' and 'come in' only to realise that the event did not concern her and occurred not even physically near her.

**Dynamics.** Although only three physical spaces were connected during phase 1 (only two were mobile), more movement than originally expected was recorded. This refers to movement in one plane, as up and down movements were rarely used. This is not to say that inhabitants were navigating constantly - far from it. However, the recorded interaction suggested that virtual movement might become (with some redesign) a suitable tool for the adjustment of the background awareness of others. What is important to reiterate here is that these interactions occurred in the context of an everyday office setting that required attention to a number of other processes and pieces of technology at the same time.

**The public MRACell.** Another observation worth noting was the lack of aural interaction across the public MRACell installed in the meeting room. A number of people in the lab stated that they glanced at it to see whether they could see someone in the other two offices but conversations were rarely initiated across this link.

There might be a number of reasons for this finding. For once, as this MRACell was designed to be the 'hearth' of the MRA, navigation was not permitted. This left people attempting to use the system from the MRL meeting room side with no way of attracting attention. At the same time no one person had ownership or control of this Cell and a number of people stated that they were often unsure whether it was on, or even whether they were allowed to use it.

To follow this up, two informal interviews were conducted with Gary and Glenda, both located in the main MRL area. Both stated that they did not use MRA a lot but did use it to quickly glance and see whether somebody in the other offices was present. They had no immediate need to use the system, as everyone connected was actually located in the same building. Gary expressed the view that the physical location and who is actually connected, is critical to the usefulness of MRA and suggested connecting Ben, who heads the MRL. Glenda, who is the administrator of the largest MRL project, suggested that many things she needed to discuss with others were in fact confidential, that she often had to discuss physical documents, and that she was simply unsure about how loud she needed to speak to be understood by others. Interaction was simply too public for her. This started to point to the fact that different locations of MRACell would have a key influence on their use and their generative effect on social interaction.

**Bypassing MRA.** The system was also bypassed for arranging physical meetings. For example, Ben walked past the MRL meeting MRACell, continued upstairs and into C9 to talk to Anne. Both then went down again to the office opposite the MRL meeting room MRACell to continue their discussion.

**Maintaining eye contact.** One of the aims of placing the camera as close as possible to the centre of screen was to allow inhabitants to maintain eye contact during conversations, although it was already clear that this was not going to be strictly possible as the cost involved in setting up a system like for example the Majic system (Ichikawa, et al, 1995) was deemed to be too high. However, what was not realised at the outset was that as inhabitants change their virtual spatial relationships and their physical position in front of their camera on their own terms, it is not in any case possible to design the system to maintain eye contact at all times. Inhabitants would have to take the initiative to align themselves physically as well as virtually and there were no recorded instances where anyone tried to achieve this, while this did not appear to hinder social interaction a great deal. This confirms the argument by Dourish et al that the mechanisms of social interaction in physical space are not an appropriate base line for that using electronic communication (Dourish, et al, 1996) and in particular that eye contact is not as important as previously thought.

**Audio nimbus.** Inhabitants broadcast audio over too large an area in the virtual space. There was also no visualisation as part of the virtual geometry that could have indicated how far audio might travel.

### **7.2.7 Summary of observations**

The data collected during phase 1 provided a very useful insight into the use of MRA in an everyday setting, while it was clear that with the small number of spaces connected MRA could not be fully evaluated just yet. There were some key issues that are worth reiterating at this point.

Within MRACells, social interaction takes place that is either ‘contained’ within physical space, or it can have an impact across MRA, especially when verbal interaction takes place between the different parties connected. The interface to people’s MRACell did prove to be inadequate; it was too slow and cumbersome. At the same time more dynamics were recorded than initially anticipated.

The privacy settings that were designed to allow inhabitants to express privacy requirements in their work environment were used infrequently as was the public MRACell in the MRLab foyer. The latter seemed to be used for ‘awareness glances’ but not much for verbal social interaction. This appeared to be due to its location but also to the lack of ownership and controls over its virtual position. Finally, it is worth reiterating that fundamentally MRA does not support eye contact well. Not only are cameras not installed in the centre of the screen but the focus of attention by inhabitants is rarely the centre of the projection anyhow, since this is not where other MRACells appear most of the times.

### **7.2.8 Changes implemented as a result of the data captured, in preparation for phase 2**

There were a number of changes that were implemented as preparation for the next phase of the prototyping activity. They concerned changes to geometry and the scale of embodiments, changes to the environment as a whole and changes to the navigation control. These will be considered in turn.

### ***7.2.8.a Changes to geometry and scale of embodiments***

The audio nimbus was limited further to prevent audio from different MRACells spilling into too much of the environment. This was designed to allow the viewing of the video of another cell at a distance (at low fidelity) while preventing audio from being transmitted at this same distance. Additionally, the extent of the nimbus was then marked out as part of the embodiment as a circle, going all around the MRACell. Inhabitants could then use this as a guide for where to position their cell to set the level of audio to what they required. When their circle did not intersect with any other circle, no audio was being transmitted, while at a full overlap, their would be full audio.

Furthermore, side panels were added in the shape of the virtual camera FOV were added. This was aimed at making clear to inhabitants where to position themselves in relation to others, depending on how much they wanted to be seen. At the same time these panels established reciprocity of visual access, as they also prevented inhabitants from seeing others without being seen. Finally, during phase 1 the MRACells, when completely closed, were hard to identify when looked at from the front. For phase 2, the room number was added in a prominent place in addition to a sign saying 'not available'.

### ***7.2.8.b Changes to the environment***

Some information was added underneath the main label for the static MRACell belonging to the meeting room. This included a list of weekly seminars, useful phone numbers and a map of the Jubilee Campus.

Occasionally, an additional radio client was added to the environment. It broadcast music in one area of the space confined by its audio nimbus. This depended on the availability of the additional machine necessary to make this happen. Associated with this was a small enlargement of the overall environment to allow space for the radio. This was simply done to add a playful element to the MRA allowing inhabitants to share music. This was peripheral to the design approach. As the audio quality was relatively poor compared to personal stereos and people located in a particular space would have had to listen to the same music, it was not used by many. It was not further evaluated.

### *7.2.8.c Changes to navigation control (joystick)*

As noted earlier, the control of the MRACells with keyboard and mouse proved too cumbersome. It was too intrusive, unintuitive and time-consuming to use. A joystick interface was added that controlled all aspects of MRA that an inhabitant needed to interact with. The joystick movements were mapped to movements around the environment. Two buttons controlled flying up and down and two buttons controlled the changes of the privacy settings.

## *7.3 Prototyping Phase 2*

During the second phase of the study, which took place between January and March 2004, four MRACells were studied. This included the three original cells as described above in addition to one extra MRACell set up in another office (see below). This phase was aimed at reflecting on the changes introduced previously in phase 1 and at identifying further changes that might be necessary to achieve a stable and useable MRA in preparation for the connection of remote sites. It was also used to investigate and report back on the levels of awareness that can be achieved in support of co-presence, which MRACells were designed to support.

During Phase 2, the underlying MRA system (MASSIVE3 environment) was running for approximately 570 hours in total, of which 215 were during the typical office hours of the MRL. During this period the system software in the Mixed Reality Lab received a major upgrade to Windows XP. This required downtime for the actual install and time for detailed testing after the install. The study was interrupted by this for about 4 weeks.

### **7.3.1 MRACells during phase 2**

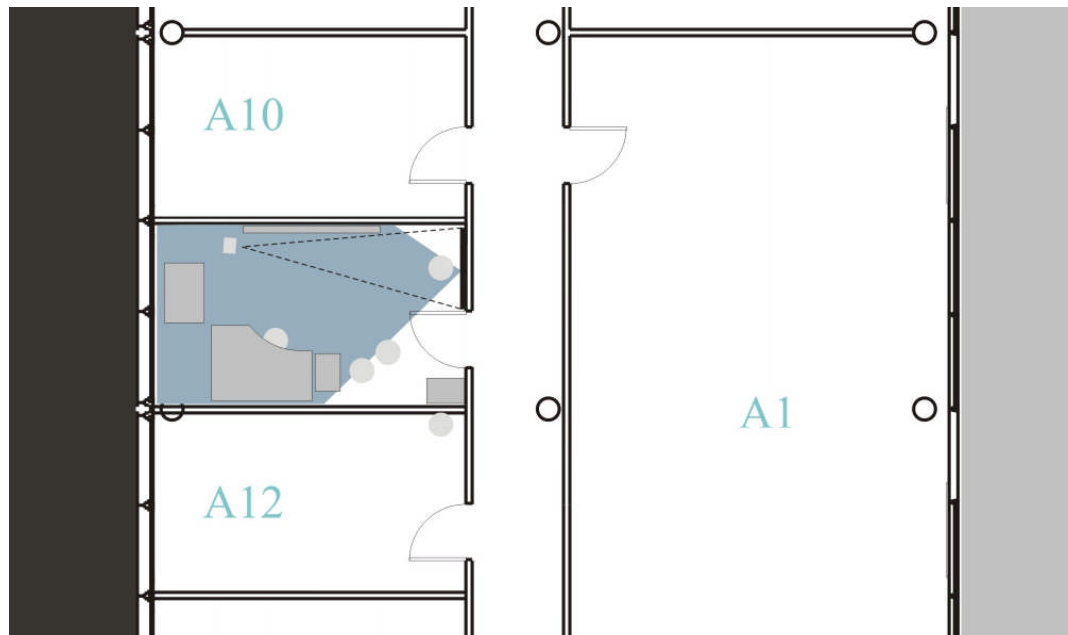
One MRACell was added and run alongside the original three cells as described previously.

#### **A11, MRL, Nottingham**

Room A11 is a single office located on the ground floor of the north wing of the building. During Phase 2 it was occupied by Sarah, a lecturer in the department. It is located on a quiet corridor only accessible from one particular side of the building and somewhat cut off from the rest of the research group. Students en-



ter A11 regularly for small group meetings and tutorials. Sarah had only recently moved from an office on C floor. The figure below illustrates the layout of A11.



**Figure 42 A11 - Plan**

Figure 43 and Figure 44 show the view from the MRA camera in A11 and the view of the MRA screen respectively.



**Figure 43 View from MRA camera in A11**

Ownership of and control over this space are with Sarah alone. Its location leads to only a few chance encounters between its inhabitant and people passing by on their way to other offices and a lab at the end of the corridor. Therefore, it was represented in the MRA virtual space with a mobile MRACell that had individual control over its privacy settings.



**Figure 44 MRACell in A11**

### **7.3.2 MRA Guide**

A guide to the system was handed out to the stakeholders in MRA for future reference (see appendix 11.2.2). Newcomers to MRA who connected at later phases also received copies. In addition, the same guide was mailed out to other members of the respective research groups. As they had some access to the system either via the public installations or through the use of one of the office ones, this information was aimed at getting them more involved in some way. This also responded to previous comments from non-stakeholders that they were not quite sure how MRA worked and whether they were permitted to use it.

### **7.3.3 Evaluation**

The main method for the study of this second phase was an observational study (see section 4.2.2). As in phase 1, the video and audio streams generated by inhabitants within MRA were recorded on tape. As MiniDV offers 120min recording time at the very most and was relatively costly, other alternatives were investigated. Digital storage would have been ideal, but at high compression and quality settings (e.g. MPEG2), the material cannot be reviewed at high speed and the synchronised replay of multiple sources would have required additional work. Instead it was decided to use professional S-VHS decks, as they were available in the MRL. These allow 180min recordings on comparatively cheap media. During phase 2, four sessions of 180 minutes each were recorded (video and audio) and analysed. Times of recording were always announced to the people directly involved. The video material consisted of the video feeds streamed

from the MRACells as seen by the system and the map, in the same way as in Phase 1, with the addition of the fourth MRACell.

### 7.3.4 Observations

The video and audio data that was captured during phase 2 allowed a more in-depth look at some of the issues recorded in the previous phase. There was also additional, informal feedback from inhabitants that was used of for the analysis of the system and subsequent changes to MRA. The focus of the evaluation was on the level of awareness supported by the current implementation as a basis for social interaction, while a number of additional observations were made that were fed back into this last phase of development before more widespread deployment.

#### 7.3.4.a *Awareness*

Awareness of others is a key concept for understanding social interaction within MRA. The MRACells, the basic units of MRA each consisting of one physical and one virtual space, have been designed to support co-presence of people located within them. Being aware of others can be said to be a pre-requisite to experiencing such co-presence.

Koleva et al have argued that awareness can be described in terms of four complementary categories (Koleva, et al, 2001). These are the awareness of the presence of others, of their identity, of their actions and finally reciprocity of awareness, the latter being concerned with whether people can understand to what extent others are aware of them. What follows is a consideration of these issues as observed in the use of MRA, with the aim of investigating the extent to which MRACells really can support co-presence.

Fundamentally, the level of awareness established in MRA depends on two things. Firstly, there is the technology that links physical to virtual space in each MRACell and secondly there is the virtual spatial relationship between two or more MRACells, where the distance between and angle to other MRACells is of relevance.

#### **Awareness of the presence of others**

Awareness of the presence of others was very well supported. When arranged close enough to another MRACell, ambient audio was transmitted between the

physical spaces connected. For example, the fact that somebody was typing was clearly audible as were the opening and closing of doors. There were many observed instances where this type of ambient audio prompted inhabitants to look up at their screen to see what was going on.

In addition to the audio, the live video stream would easily allow awareness of the presence of everyone in camera view but also the state of the automatic room lights fitted in the Computer Science building. Those are timed to switch off after 20 minutes if no movement has been detected in a particular room, allowing others to infer how long somebody has been away.

Movements at a large enough scale across an inhabitant's screen can register in somebody's peripheral awareness. When an inhabitant moved their MRACell close to another one, or if they were already close by and they physically moved in their space, this would register as quite substantial changes in the image projected in the remote space. As this occurs, the level of light emitted from the projector changes, causing a change in the overall lighting in the remote space. Both these were observed to register in inhabitants' peripheral vision.

Finally, another behaviour that was recorded was inhabitants making themselves aware of others in a much more active way. There were a few instances when inhabitants left their virtual spot, which they might have occupied for a while, only to navigate to one or two other MRACells to see what was going on in those. They did not necessarily stop for a conversation but only glanced into a space and then moved on.

### **Awareness of the identity of others**

Awareness of the identity of others was supported less well. The video quality was relatively poor at only 160x120 pixels. However, most of the time, video quality did not impede the identification of someone across MRA since people knew who was most likely to appear in a particular space. Each MRACell was clearly labelled with a room number and names of occupants and the number of cells was limited to four. But there were instances when people asked who had appeared in front of the camera in another space and in these cases a deliberate action was needed to identify them. Overall this did not appear to cause many problems.

### **Awareness of the actions of others**

Awareness of the actions of others was supported in three different ways. As mentioned above, the transmission of audio allowed access to some information about activity (e.g. typing, phone use). The audio levels were tuned so that conversations could only be understood when directed at the microphone. Video would allow others to see activities in view of the camera like people having meetings or looking at the screen in contrast to reading a book, for example. At the same time, what people were doing exactly (e.g. screen or book content) was not available to others. Finally, movements through the public virtual space clearly were an activity that could be seen by others, if they faced in the right direction. Where and when others moved, and where they located themselves virtually after moving, allowed some access to their intentions.

### **Reciprocity of awareness**

MRA is designed to be symmetric in terms of the access it offers each inhabitant to the overall experience with the explicit aim of establishing reciprocity of awareness between them. Each inhabitant is represented in the same way, an embodiment representing their room and live video and audio representing themselves within this space. To 'enforce' MRACells to be positioned so that awareness was reciprocal, the side panels of the MRACells were introduced. They prevented inhabitants from viewing somebody else's physical space without being in view of them. However, instances were recorded where inhabitants located their cells in positions that would make them visually available only in part to their counterparts. While the FOV of MRACells was clearly marked out through their geometry in 3D space, this becomes less clear when others are located some distance away and it is then more difficult to find a good viewing position, especially once the 3D information has been translated to a 2D screen.

What needs to be born in mind though is that the physical interfaces to MRA were installed slightly differently in each of the offices as well as in the public space. In addition, in none of the installations was the FoV of the physical camera enforced or even marked out in physical space, although it was clearly indicated by the video view of one's own space (see Figure 40). Physical side panels equivalent to the virtual ones incorporated into the virtual representation of the MRACell would have been necessary to enforce this. This influenced the mutual awareness between MRA inhabitants, depending on where inhabitants were

physically at a particular time. For example, one office might allow inhabitants to be off camera, while the set-up in another office might make this very difficult. Overall though, once people are located in the same physical location within the FoV of their camera, reciprocity of awareness is given.

#### **7.3.4.b Other observations**

There were also a number of other observations, concerned with the role of MRA among other channels of communication, the use of the public MRACell, the environment map and explanations given by inhabitants to others.

##### **Channels of communication**

The observations have shown that one way of describing MRA is as a communication channel among others that are available to inhabitants at the same time, like email, the phone and very importantly during phases 1 and 2, meeting physically within the Computer Science building. This fact might have had an influence on the length of interactions. During phases 1 and 2 only a few conversations were recorded that lasted for more than a few minutes. It appeared that MRA opened an additional channel of awareness and communication that was sometimes used directly and sometimes indirectly to establish communication across a different channel. As will be shown later this pattern then changed with the installation of remote MRACells.

There were also many instances when the use of MRA conflicted with the use of the phone. However, the joystick interface now made possible a seamless transition between the two, when inhabitants would pull away virtually while grabbing the phone with their free hand. Inhabitants would also leave the audio range of others before making phone calls, as a pre-emptive measure.

##### **The public MRACell**

Just as in phase 1, the MRACell located in the public MRL meeting space was least used. It remained fixed in the virtual environment, while it was located in a prominent place virtually as well as physically. Its physical location certainly provided enough opportunity for interaction. For example, over one three hour period more than 65 instances were recorded when somebody (often the same person a number of times) walked past without directly engaging in an interaction across the system or re-configuring the MRA to make such an interaction possible.

However, looking in the other direction, there were instances where the ability to view the MRL corridor was used to approach people passing by. For example, inhabitants of C9, when located virtually close to the MRACell of the MRL, called across to involve Rico into a short conversation. Rico is one of the people heading the MRL but is frequently away, and it appeared that for that reason it was worth waiting virtually near by the public MRACell to be able to speak to him.

### **Map**

During phase 1 and 2 the live map of the environment was relatively hard to read. The main reason for this was the limited resolution it could occupy on the projected screen image, effectively restricting it to roughly 250x185 pixels, independent of what was actually transmitted. It also appeared with too little contrast and colour saturation. It was felt that it might therefore not be used much.

At the same time it did not seem to be redundant. Sarah commented negatively on the unavailability of the map when the MRACell was set to semi-private or private. In addition, Kate, when prompted, stated that she did use it for seeing where others were, how they were aligned and for deciding how far to move away from others so as not to be in their audio range.

### **Explanations**

Inhabitants gave very detailed descriptions of MRA to interested visitors. They had been asked to alert visitors to the MRA setup especially during times of recording, but sometimes the descriptions went beyond that. The separate parts of the projected interface were explained as well as the frequency and types of uses, which also showed that inhabitants had a very good understanding of the functionality of the system.

### **7.3.5 Summary of observations**

The data collected during phase 1 provided a very useful insight into the use of MRA in an everyday setting, although it was clear that with the small number of spaces connected, MRA could not be fully evaluated just yet. There were some key issues that are worth restating at this point.

This second phase of the study provided more feedback about the use of MRA and the changes introduced in the previous phase. An additional local MRACell had been incorporated into the overall MRA without difficulty in this phase and

it was felt that MRA was ready for general use and therefore for deployment outside the Mixed Reality Lab. Observations during phase 2 showed that people located within MRACells could be aware of each other in terms of each other's presence and identity. The awareness of actions of others was also supported but to a lesser extent, and the reciprocity of awareness was found to depend on the exact virtual position of MRACells relative to each other but also on the actual physical setup in each of the different MRACells. In addition there were some other observations. Firstly it is clear that MRA is used as one of a variety of communication channels. Secondly, the public MRACell was still used most infrequently for verbal interaction. However, it was used to remain generally aware of events and it was used in this way by people located in its physical part as well as by people located in its virtual part. Thirdly, the map had some clear problems, but was nevertheless used by inhabitants. Finally, explanations of MRA given to visitors to MRACells were often very detailed and demonstrated the good understanding that inhabitants had of the MRA itself.

### **7.3.6 Changes implemented as result of data captured**

As a result of the observations described above, there were a number of small changes that were implemented as preparation for the long term study of MRA.

#### **7.3.6.a *Changes to the interface***

As the map had been reported by two inhabitants to be useful it was retained. The brightness was increased and the colours in which the MRACells were displayed were corrected to better reflect their privacy settings. The map was also made available at all privacy settings, so that a low level of awareness of events in MRA could be maintained although the virtual side of the MRACell was actually closed.

Additionally, the public MRACell in the MRL foyer was given virtual mobility, which had been requested by people located in the MRL main lab space. Like the other MRACells it was also equipped with a joystick, aimed at encouraging more interaction at this location.



### ***7.3.6.b Other changes***

The overall space of the virtual environment was enlarged to allow all clients to find enough space. Some information was added for each site, like for example phone numbers of people inhabiting a particular MRACell. Because the video now had to be transmitted outside the local area network, the video technology was changed to use VIC, a multicast video streaming application available from UCL, which offers variable rates of compression. Finally, on request by inhabitants a red dot was added to the environment map when recordings were taking place.

## ***7.4 MRACells as set up for the final prototype***

Based on the observations above and the resulting changes to MRA, it was decided that it was ready for expansion to remote sites. One MRACell was physically relocated twice (June and October 2004), one was added in June 2004 and one was added during July 2004. The other three MRACells, as described in the previous sections remained.

### **4.9, 3 East, Psychology, Bath**

Sarah, occupying A11, Nottingham during phase 2, changed jobs during the study and moved to the Psychology department at Bath University. Here she occupied two different offices during phase 3 of the study. Her MRACell was installed in both of them but in different configurations. 4.9 is a very small single office located on the 2<sup>nd</sup> floor of building 3 East on the Bath University campus. It is located in a separate building from most of Sarah's colleagues in the department, and is somewhat cut off. This and the fact that Sarah had only just started the job meant that traffic was limited. There was no teaching at this period and students did not have to come to the room yet. The figure below illustrates the layout of 4.9. Ownership of and control over this space are with Sarah alone. Its location could potentially lead to a limited number of chance encounters between Sarah and people on their way to other offices. However, because of the reasons mentioned, it did not. It was represented in the MRA virtual space with a mobile MRACell that had individual control over its privacy settings.

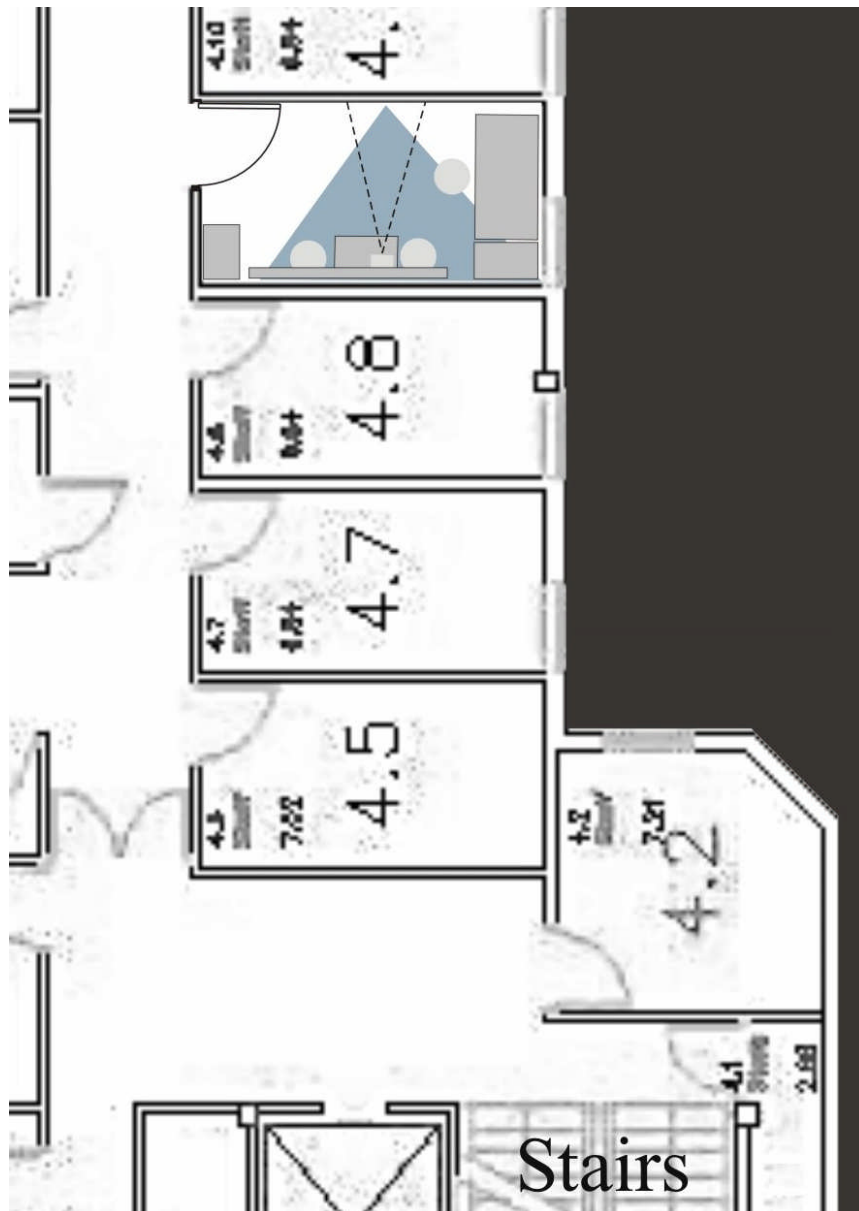


Figure 45 4.9 - Plan



Figure 46 View from MRA camera in 4.9



**Figure 47 MRACell in 4.9**

The set-up was somewhat temporary as it was clear relatively soon that Sarah would move to a slightly larger office in the main Psychology building. Also as the office was so small and choices for locations within it very limited the screen image was small in comparison to all other set-ups.

#### **1.2a, South, Psychology, Bath**

By the end of September 2004, Sarah had moved to the new office. Room 1.2a is a single office located on the first floor of the South building. It is within the main Psychology department with a number of colleagues located on the same corridor. Here a little more space is available and the location was going to be more permanent for Sarah. Because this office was much more central and Sarah started teaching in her new post, much more traffic was generated and colleagues and students would enter regularly. The figure below illustrates the layout of 1.2a.

Ownership of and control over this space are with Sarah alone. Its location leads to a limited number of chance encounters between Sarah and people passing by. 1.2a was represented in the MRA virtual space with a mobile MRACell that had individual control over its privacy settings, just like the previous installation in room 4.9.

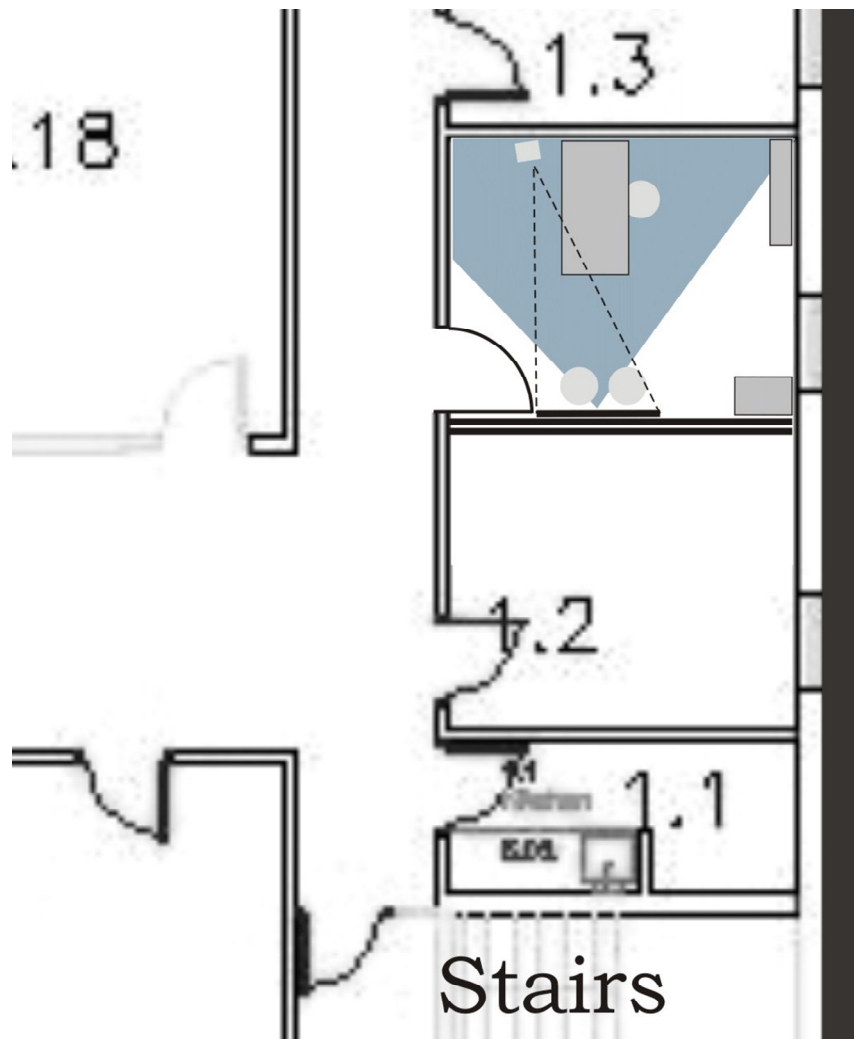


Figure 48 1.2a - Plan



Figure 49 View from MRA camera in 1.2a



Figure 50 MRACell in 1.2a

### 332, VRCentre, Bartlett Graduate School, London

Room 332 is located on the third floor of the Bartlett Graduate School at University College London. It serves as an entrance area to the VRCentre research group and provides access to two offices and a corridor beyond, which in turn links to another 5 offices.

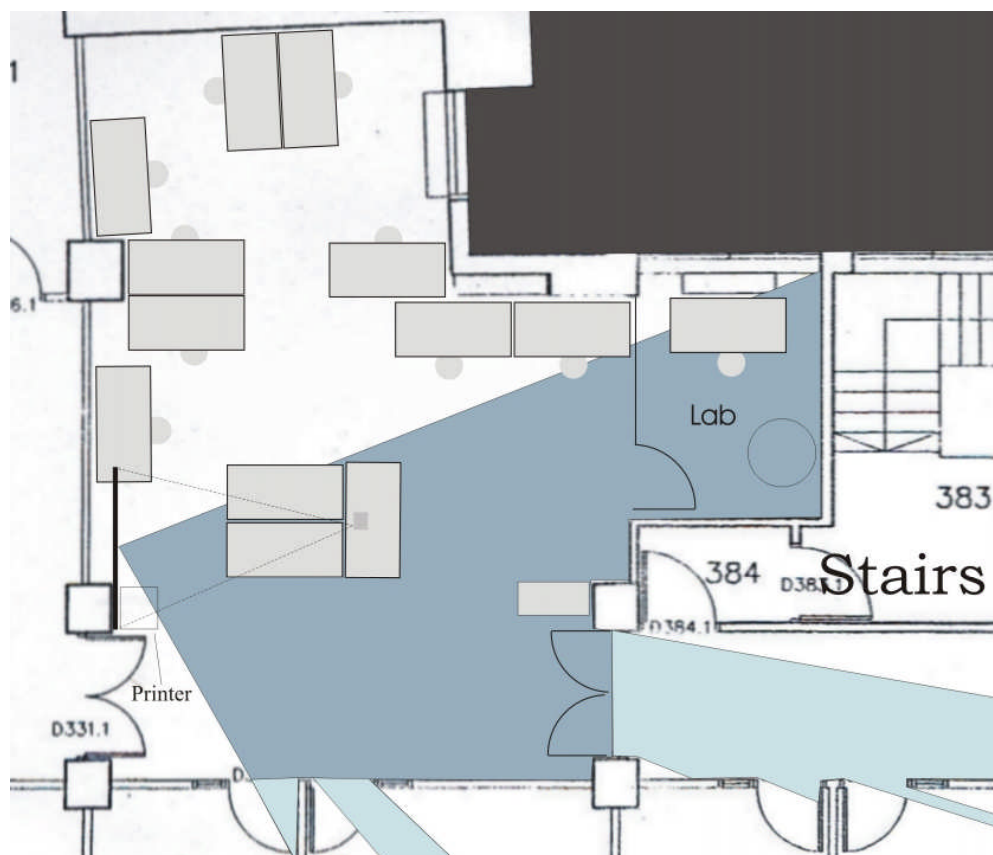


Figure 51 332 - Plan

It contains a small space for the research group as well as the main laser printer and desk space for around 10 researchers. A small experimental lab is accessible

only through this space. As a result of its position and layout, it is a room that often leads to chance encounters between people during a normal working day. The figure below illustrates the layout of 332.

The two figures below show the view from the MRA camera in 332 and the view of the screen installed there.



**Figure 52 View from MRA camera in 332**



**Figure 53 MRACell in 332**

Similar to the MRL meeting room in Nottingham, 332 can be described as central to the research group. People working in the VRCentre will pass through this space at least once per working day and a number of researchers have their main desks there.

There appears to be no clear ownership of the overall space but individual researchers take ownership and control of the separate work bays within the space. This, combined with the different types of uses that room 332 needs to cater for, sometimes leads to conflicts between different activities. A meeting around the



table for example might well interfere with someone concentrating on a piece of work at their own desk. Regarding the MRA installation it was likely that no one would take full responsibility for the set-up in a similar way to the MRL meeting area. Room 332 was represented with a mobile MRACell that had shared control over its privacy settings.

### **127C, CS, UCL, London**

Room 127C is a single office located on the first floor of the Computer Science building at UCL. It is occupied by Scott, a lecturer in the department. It is located off the main open plan office, which provides desks for researchers and graduate students. It is at the far end of this space away from the entrance. Scott's colleagues and students enter 127C regularly for meetings. The figure below illustrates the layout of 127C.



**Figure 54 127C - Plan**

The following two figures show the view from the 127C MRA camera and a view of the screen installed in that office.



**Figure 55 View from MRA camera in 127C**



**Figure 56 MRACell in 127C**

Ownership of and control over this space are with Scott alone. Its location leads to a limited number of chance encounters between its inhabitant and people passing by. It was represented in the MRA virtual space with a mobile MRACell that had individual control over its privacy settings.

#### **7.4.1 The set-up process**

Finally, it is worth briefly looking at the set-up process itself as it has emerged over a relatively long period. MRACells were set up when they were added to the overall MRA. Originally there were only the three MRACells situated in the MRL at Nottingham. The other three were added later in a staggered fashion. The MRA therefore grew slowly over several months. The details of each individual set-up were decided at those times. How this was done and what was considered is described in detail below.



### **Decision making**

Originally, individuals were asked whether they would like to be part of MRA and when they agreed, an MRACell was installed in collaboration with them in their own space. Later on, MRACells were installed on request, as others became interested in being part of the community. Here the person making the request would do so for their own space as happened with 127C or for a general space that was occupied by somebody else as happened with 332. The person heading the group originally requested the installation, while not having his work space there himself.

### **Collaboration**

The set-up occurred in a close collaboration between the author and the inhabitants of the respective spaces. These were individuals as in C54, small groups of colleagues as in C9 or larger groups of people as in 332 at the Bartlett. The author took an advisory role in this process, but the inhabitants had the final say.

### **Mobility**

One unexpected aspect of the installation process was that a number of installations had to be moved. Sarah moved her MRACell installation twice: first from Nottingham to Bath and then from her first office there to a second office. After the main study period, Scott and his group moved buildings. He took his MRACell installation with him and reinstalled it in the new building. The hardware set-up for MRACells was not designed with this in mind. Although much simpler than the original installation, a reinstallation still required moving a number of pieces of equipment like the computer, the camera, the projector etc. separately, before reassembling them in the new space. As this level of mobility was not anticipated, the equipment had not been greatly integrated. However, the fact that inhabitants were prepared to spend the time required to move installations, appears to point at their commitment of remaining part of the community of which they had become part of.

### **Location**

As a next step, a suitable location for the technology had to be found in each of the offices. This was constrained mostly by the existing layout of a room, which was usually not adapted for MRA. The size of the projection screen and the distance required between screen and projector were further major factors. This meant that there were usually only between one and three suitable positions in

any of the participating spaces. Often this would be the largest section of unused wall surface.

### **Orientation**

Closely intertwined with the decision on how to position the interface was the resulting orientation of the screen and the camera located on the screen surface. What the camera could then see of a particular space was a very important consideration. The effects of different orientations will be discussed in section 9.1.1.c.

## ***7.5 An ‘inhabitable’ Mixed Reality Architecture***

The survey that was outlined at the outset of the chapter has shown that the settings chosen were very suitable when considering the existing social networks. Following this, the installation of the different MRACells, the technology underpinning MRA and the evaluation methodology have been discussed. The two iterative cycles of prototyping then started to show how inhabitants conducted their everyday work activities within MRA. In particular, it has been shown that awareness of others is supported to the extent that MRA allows the integrated physical and virtual spaces of each MRACell to be described as supporting co-presence. There were also a number of smaller, detailed changes to various aspects of the implementation with the aim of creating an MRA that was stable and useable by inhabitants. Overall the observations show that this has been achieved and that the final prototype of MRA was ready for deployment outside the MRL and for more persistent and everyday use.

# 8

## Study 2: Mixed Reality Architecture Observational and Statistical Data

This chapter presents the data collected during the evaluation of the final prototype, which took place between July and October 2004. This material mainly consists of ethnographic vignettes that describe social interaction in dynamic MRA in detail. This is complemented with statistical data generated from the MRA system logs. For this main study period, MRA was running for 59 days not counting weekends and public holidays, which amounts to 472 hours during the typical office hours of the MRL.

Altogether, six MRACells were installed. Three were located at the MRL in Nottingham, one was located at the Psychology department in Bath, one was located at the VRCentre in London and one at the Computer Science department in London. There were two public spaces, one shared office and three single offices, all

with different properties in terms of ownership, control and privacy requirements. The six spaces were distributed across three cities, while the original three MRACells were still in the same building in Nottingham and therefore local to each other. In their entirety, they then represented well the intended target application in physically distributed organisations.

For this final phase of the study of MRA, two methods were used. The main method was an observational study (see section 4.2.2). This was supported by recording and replaying virtual environments (see section 4.2.5). The combination of these two allowed the production of vignettes, describing a selected group of interactions in very fine detail with the aim of abstracting larger issues from these. In addition, the analysis in general was also augmented by more informal feedback from inhabitants and information drawn from the diaries that some inhabitants kept of key events. Additionally, the data logs recorded within the virtual environment allowed quantitative analysis of patterns of use over longer periods, than the observational study allowed. The different methods and results will be outlined in what follows.

## 8.1 *Observational Study*

In a similar fashion to phases one and two of the study, the video and audio streams generated by the system were recorded on tape remotely. To be able to record all six MRACells, this now involved two S-VHS recorders. These were connected to a dual-head graphics card on the computer generating the panelled arrangement of views into MRA shown below.

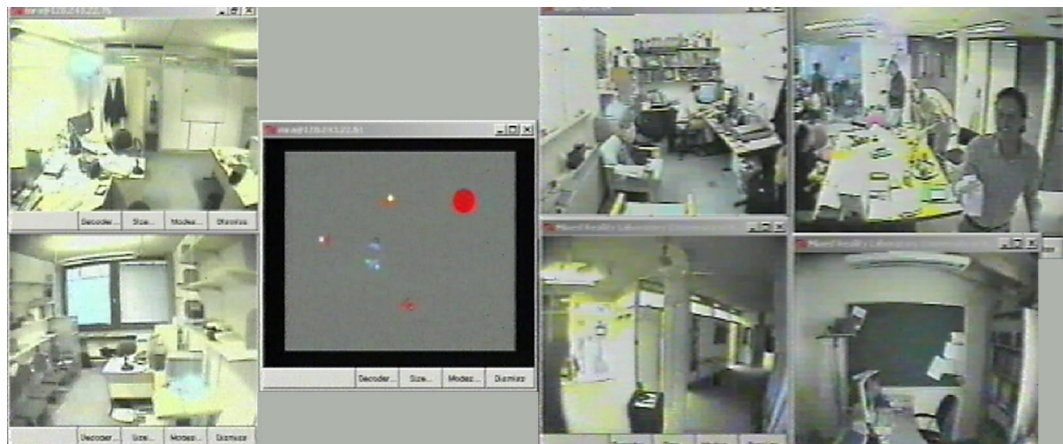


Figure 57 Two screens of recorded video material including map

Times of recording were always announced to the people directly involved. The video material consisted of the video feeds streamed from the MRACells and as seen by the system in the same way as during phases one and two. Just over 28 hours of material was recorded (video and audio) and analysed.

As has already been mentioned, the information recorded in this way was then augmented by the MRA data logs. Over long periods during the up-time of MRA, all events as seen by the underlying MASSIVE3 system were recorded using the Record&Replay technology. Specifically, all the periods that were recorded on video tape for use in the observational analysis were also recorded as system logs for comparison and cross-referencing. This included the audio streams but not the video, as will be explained below. Overall just over 680 hours were recorded in this way (this figure includes some weekends and public holidays).

In contrast to the video tapes with only one audio track, the audio streams were recorded in their original spatialised state. This allowed their separation and a more fine grained analysis of interaction, compared to the video tapes where the audio sources were overlaid onto a single track. However, within MASSIVE3 Record&Replay there was no facility to retain the video streams. Although this would have been valuable in certain instances and definitely for the later presentation of material, the analysis of the video is probably even easier when spread out in a 2 dimensional way.

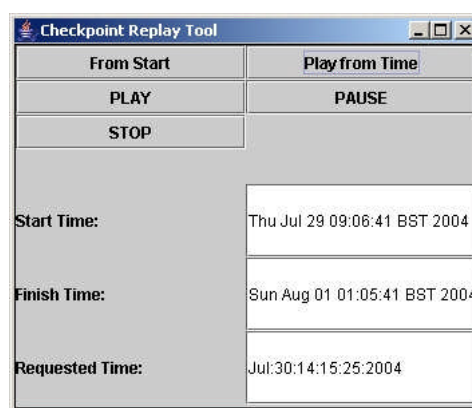


Figure 58 Record & Replay Interface

Each MASSIVE3 recording consisted of a monolithic ASCII file and an associated audio file, if audio recording had been specified. These files then needed to be checkpointed to allow the playback of defined sections rather than of files in their

entirety. After identifying relevant sections on the video recordings, the associated points in the MASSIVE3 recording were lined up and could then be played back using the interface shown in Figure 58.

This allowed the review of the recorded material as a map or in perspective view as shown in Figure 59 and Figure 60, respectively. The map below shows all six MRACells and their configuration on July 30 2004 at 14:15:25. For greater clarity, the textures have been removed from the environment. Apart from the configuration, the privacy setting can also be clearly read. One MRACell has its front closed, shown in red on the map. The others are all set to open, shown as blue, while none of them is set to semi-private, which would be displayed as yellow.

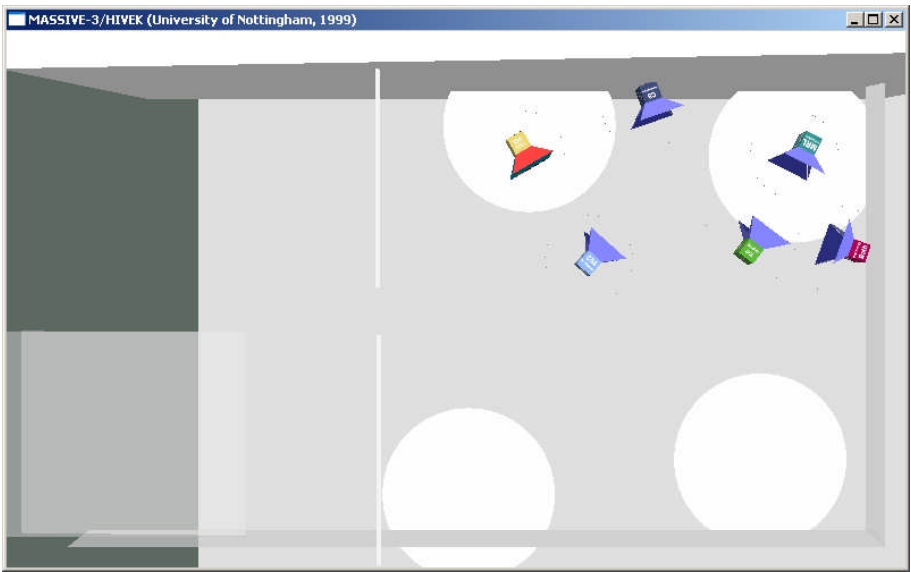


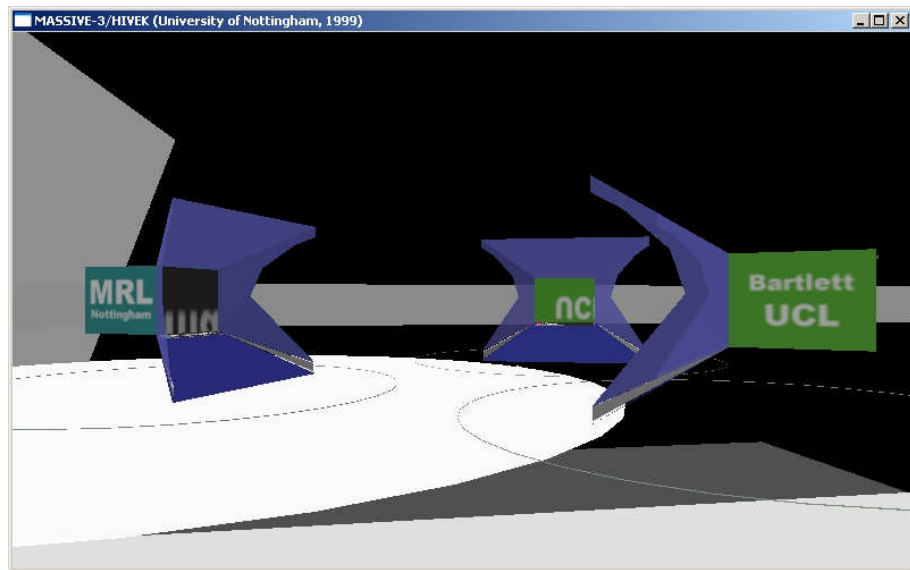
Figure 59 Record & Replay Map View

The six MRACells were all colour coded and the following table provides an overview of what they look like on the map in their open state, which can also serve as useful overview for reading the results presented in the following sections.

C9	C54	MRL	Bath	Bartlett	CS UCL

Table 13 Six MRACells as displayed on map

Figure 60 then shows the perspective view into MRA that can be taken to analyse the material further and it also clearly shows that video cannot be played back as it originally appeared within the environment.



**Figure 60 Record & Replay Perspective View**

The recorded material served two specific purposes in the analysis of MRA. Firstly, it supported the observational study of MRA by providing spatial information not otherwise recorded. Although the video recording already contained a map view of the MRA (see Figure 57), this had a number of problems. As it was based on the same video stream that was made available to inhabitants on their interfaces, it was relatively unclear and had a considerable delay and a low frame rate. In addition, it provided only a single view point: a map view. The MASSIVE3 recordings however, allowed a clear, high frame rate review of the material from any chosen view point, crucial for a more fine grained analysis. For example, Figure 60 shows that three clients that are relatively close to each other in one corner of the overall environment. From this view it can be inferred that the UCL and the MRL client had an unobstructed view of each other's video, while the third client would have only had a very oblique view into the other two. It can also be seen that at that point audio was not transmitted between any of them as they were too far apart from each other; the audio circles did not intersect.

The main challenge in the analysis of the material was then to bring those two sources together for the preparation of detailed excerpts or vignettes of selected periods of interaction. To gain a good overview of the material, the analysis involved going through the video material on tape in parallel with the replay of the MASSIVE3 recordings. This required frequent manual re-alignments not helped by inconsistent recorded dates and times. As a next step this overview was captured in a spread sheet designed around a basic time line. A small excerpt of one of the spread sheets is shown in the figure below.

### Figure 61 Spread Sheet: Overview of Events

## Study 2: Mixed Reality Architecture Observational and Statistical Data



der and given a small descriptive label. This level of detail was documented for the full set of tapes recorded during this phase.

### 8.1.2 Vignettes

As a next step selected periods of material were subjected to a much more detailed analysis and what follows is one of the vignettes generated in this way. Each vignette begins with its title which is followed by information on the date and time the material was collected. A short overview of the context is provided. Then a detailed description is provided of events including talk, video stills and maps. Annotations were made to indicate that two spaces were communicating with each other and to relate video stills to map positions. Finally, an analysis of the material follows. For anonymity, all names have been changed. The author appears as 'Sam'.

The following section includes Vignette 1 completely to give a full impression of what the collected material is like. For brevity, only the introduction and analysis of Vignettes 2 – 8 have been included below, but they can be found in full in appendices 11.2.3.b - 11.2.3.g .

#### 8.1.2.a Vignette 1 – Establishing and concluding communication

Date	Start time	Duration
29/07/2004	13:30:19	5 min 2 sec



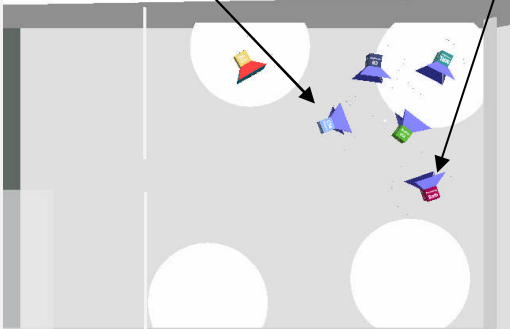
##### **Context**

This vignette describes a very typical set of behaviours that occurs when one inhabitant takes the initiative to speak to another. Sarah (SD) re-configures MRA to bring the 4.9 MRACell close to the C54 MRACell. A conversation between Sarah and Kate (KB) ensues covering a number of work related and non-work related issues. At the end of this conversation Sarah and Kate pull back their respective MRACells, re-configuring the MRA again.

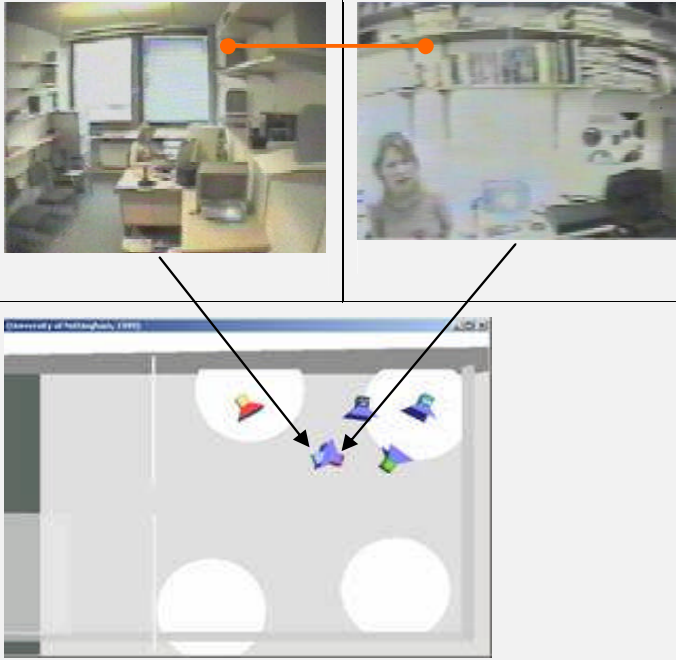
##### **Vignette**

At the outset, the C9 and C54 MRACells are arranged in an open triangle leaving space for a third party to join. Sam and Kate are working at their desks. The Bath MRACell is set back, open and Sarah is working at her desk. The Bartlett and MRL MRACells are located in one corner of the environment, facing each other. No one appears in camera view in either of those two. The 127C is set back,

closed and no one appears in camera view there either. This vignette mainly concerns the C54 and Bath MRACells. Sarah turns away from her desk and grabs the joystick, facing the projection screen.

Time:	13:30:19		
Room:	C54	4.9	
People	KB	SD	
			
			

From the starting position, Sarah moves the 4.9 MRACell over to the C54 MRACell. Once close enough, Sarah initiates a conversation with Kate.


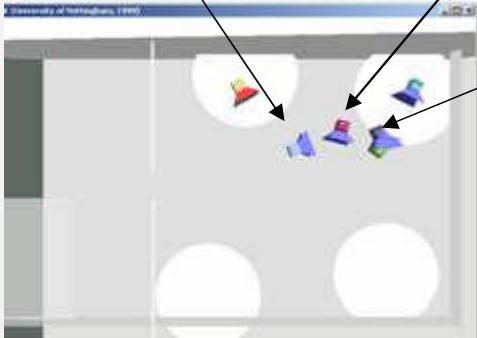
Time	13:30:30		
Room	C54	4.9	
People	KB	SD	
			

1	SD	Hi Kate	KB looks up
2	KB	Hello, how are you?	
3	SD	Not too bad, how are you?	
4	KB	Ah, ... ok, it's a bit quieter now	
5	SD	Did you get your proposal done?	
6	KB	Yeah, submitted it. [(Inaudible)]	
7	SD	[Oh, that's nice to get it out of the way.	
8	KB	Yeah, I am not feeling very motivated now to do stuff.	
9	SD	I am not surprised. It's summer. Are you having some holi-	
10		day soon?	

The conversation continues for approximately 4 minutes, covering work-related and non-work related issues, during which the MRA is not re-configured. Sarah then initiates the end of the conversation.

11	SD	Well, I shall disappear, leave you to it.	
12	KB	OK, see you later	
13	SD	Speak to you soon, bye	

At that point, both inhabitants grab the joystick and pull backwards away from each other and find new positions for their MRACells in the virtual environment. SH can be seen navigating at the same time.

Time	13:35:21		
Room	C54	4.9	C9
People	KB	SD	SH
			
			

## Analysis

This vignette illustrates two aspects of the use of MRA: how social interaction is typically initiated and ended within MRA as well as how the difference in orientation between MRA interface and main desktop PC interface is a useful resource for others.

Often inhabitants leave their MRACells in a place that allows a view of the environment but is not close enough to another MRACell to allow conversations to take place. This results in at least one of the inhabitants having to take the initiative to move their MRACell closer to another, if they want to talk to somebody. Here, Sarah moves the 4.9 MRACell close to the C54 MRACell and initiates a conversation. The conversation is not directly relevant here but not dissimilar from a conversation people might have on a physical corridor.

Once the conversation has ended, the MRA is reconfigured again. Both parties pull backwards, keeping the other party in view. This appears to be a result of the interface used: a joystick allows backwards movements just as easily as forwards movements. It also allows inhabitants to see where the other MRACell is being moved and whether they have actually left their audio range. However, a

side effect is that when pulling backwards, inhabitants often don't see that they might affect the privacy of another MRACell that is behind them.

It is also notable how both Kate and Sarah change orientation to use the interface to MRA. Both have got their main computer at about a 90 degree angle to the MRA interface. When Sarah faces the MRA to start navigating to C54, her workstation is to her right (panel 13:30:19). When she reaches C54, Kate is facing her workstation (panel 13:30:30) but then turns around to face the MRA screen (similar to panel 13:35:21). The relative orientation of workspace and MRA interface is a result of the exact set-up in each of the offices which in turn depends on local requirements and constraints. However, this difference in orientation makes it very clear to others connecting to a particular MRACell which interface a person is attending to at a given moment.

#### **8.1.2.b Vignette 2 – Chance encounters and awareness**

Date	Start time	Duration
26/10/2004	10:38:57	3 min 40 sec

##### **Context**

This vignette comprises two different interactions. The first is a chance encounter at the public MRL MRACell, when Sam (SH) 'catches' Gavin (GT) walking past and involves him in a conversation. The second directly following on from the first is when Gavin navigates around in the MRA to discover that Scott (SA) is busy and discusses this with Sam. For the body of this vignette, please refer to appendix 11.2.3.a.

##### **Analysis**

This vignette demonstrates two different aspects of inhabiting MRA: chance encounters and awareness of activity.

##### *Chance encounters*

As Gavin enters the MRL foyer, Sam spots him and initiates a conversation. By walking through the public MRL foyer, Gavin makes himself available for contact and this is made use of by Sam. Although Gavin is being interrupted on his way to the main lab space, he does enter into the conversation.

The above interaction is made possible by the previous re-configuration of two MRACells, which had been initiated by Sam before anyone was in view in the MRL foyer. The positioning of the C9 MRACell in such a way allows Sam to be

aware of events in the other space and this is then made use of to initiate the interaction. As the two MRACells are virtually close by, the video is clearly visible and audio is being transmitted. For example, it is clearly audible that somebody opens the main door and then enters the room. This interaction is also noteworthy because a private MRACell (C9) and a public MRACell (MRL) are involved. Relatively few interactions (in comparison to other MRACells) have been recorded there. The MRL foyer is mostly a circulation space and people do not tend to spend much time there. Also, it does not belong to anyone in particular, which means that others connected to it across the MRA cannot generally know who they might bump into. However, this vignette demonstrates that chance encounters do take place, although relatively infrequently as is evident from the other data collected.

In summary, chance encounters in MRA are dependent on the pre-existing topology and they are dependent on physical movements of inhabitants through that topology. This topology might be a result of a planned re-configuration, for example when two MRACells are brought close together for a specific purpose and then left there. The topology might also have emerged over a longer period with many individual decisions leading to a configuration that brings at least two MRACells in proximity. When such a topology exists, chance encounters between people can occur when they pass through the physical part of the connected MRACells. If such a topology does not pre-exist, planned re-configuration is necessary to establish social interaction.

What this vignette does not show is another type of chance encounter that one might expect to see in MRA: chance encounters in the public virtual space that are dependent on virtual movements. These could occur, if two or more MRACells were to be moved at the same time and through this movement, people navigating their MRACells encountered each other in virtual space. The recorded material does not suggest that this type of chance encounter is taking place. This is very likely a result of too few MRACells being connected in this study to make this happen

#### *Awareness of activity*

Gavin reconfigures MRA to allow him to glance into 127C, by virtually moving the MRL MRACell. Scott can be seen at his desk, turned away from camera and screen. Gavin moves in relatively close, clearly within audio range of 127C, but

does not attempt to start a conversation. Scott remains unaware of this and continues working (panel 10:41:13). That Gavin is aware of the activity of Scott becomes clear, when he reports back to Sam stating that he didn't speak to Scott because he was busy (66). Gavin is clearly aware of Scott's general activity.

At the same time the virtual movements of GA with the MRL MRACell are also clearly available to others present in the MRA. While Gavin is re-configuring MRA, Sam is looking on. Sam then interrupts his activity (going to get coffee) as he sees Gavin navigate back towards him. This prompts Sam to re-open the C9 MRACell and wait for Gavin to manoeuvre the MRL MRACell back into audio range, when a conversation between the two begins.

To summarise, what this shows are two ways that MRA can support awareness of activity. The first example shows how people can be aware or can make them themselves aware of activities taking place inside other MRACells. The second example demonstrates how inhabitants can be aware of activities taking place inside the virtual environment, meaning that they are aware of the re-configuration of MRA that might be ongoing.

### **8.1.2.c Vignette 3 – Setting up MRA for the meeting**

Date	Start time	Duration
29/10/2004	12:39:14	2 min 31 sec

#### **Context**

In this vignette Sam sets up the MRA for a meeting between Sarah (SD), Karl (KD) and Rico (RT), which has been arranged previously. Karl and Rico are not permanent inhabitants of MRA and are planning to use the C9 MRACell for the meeting. Sam re-configures the MRA to discuss the practicalities with Sarah, as he had not heard from either Karl or Rico. At the end of this interaction, he leaves the C9 MRACell ready, in view of Bath and open, so that the meeting can start smoothly. For the body of this vignette, please refer to appendix 11.2.3.b.

#### **Analysis**

This vignette allows a closer look at two separate issues. Firstly it shows what is involved in setting up the recording of MRA for analysis and secondly it shows an instance where MRA is being arranged for use by others at a later stage.

### *Recording*

At the beginning of this vignette the work involved in making a recording of MRA is shown. Sam sets the two S-VHS recorders to 'record' and then adds the red dot into the environment map, which appears on all the participants' screens. He then walks back to the recording decks to check that audio is coming in from the six different sites. This is done with the headphones that are connected to one of the decks. For easier reference later, he then speaks the date and time on to the video tape (line 1 – 2) and alerts Beatrice and Gemma that recording is taking place (line 3), before fitting the warning to the door.

The times of recording MRA were always announced well in advance to all inhabitants. In this particular instance, Sarah does not seem to be aware of the fact and reacts with surprise (line 21). However, the red dot does appear to do its job as no talk is recorded that discusses the recording with her. Sarah then affixes the recording notification to the outside of her door.

### *Arranging*

A meeting has been previously arranged between Sarah, Karl and Rico. It is one of a series of meetings taking place directly (for a while) after the weekly Friday seminar in Nottingham. For this purpose, Karl and Rico have agreed to use the C9 MRACell, as they are not permanent inhabitants of MRA.

The inhabitants of C9, Sam, Beatrice and Gemma are on their way to lunch. It appears that Sam has not been given any more details about the timing of this particular meeting and sets out to find out more. To this end, he re-configures MRA and speaks with Sarah. After discussing the details, Sam follows the others to lunch. He leaves the C9 MRACell open (line 44) and moves it back out of audio range but still in sight of the Bath MRACell (panel 12:41:45). This is also requested by Sarah (lines 49 – 50). The C9 MRACell is now in a state where Karl and Rico, who are relatively inexperienced in the use of MRA, can start using it without too much difficulty. Here the MRA has been pre-configured by one individual to be used by others at a later stage.



#### 8.1.2.d Vignette 4 – An arranged meeting

Date	Start time	Duration
Friday 29/10/2004	12:53:06	16 min 48 sec

##### **Context**

Karl (KD), Sarah (SH) and Rico (RT) have agreed to have a PhD tutorial in the MRA. Karl and Rico are not permanent inhabitants of an MRACell and have arranged to use the C9 MRACell instead. On his way to C9, Karl briefly checks out the MRA from the MRL MRACell. He then enters the C9 MRACell and is acknowledged by Sarah. She then moves a little closer.

As Rico is not available, the meeting proceeds without him. When the inhabitants of the C9 MRACell, Sam (SH), Gemma (GA) and Beatrice (BS) return from their lunch, the meeting only continues for a little while, before Sarah and Karl agree to attempt the meeting again with Rico about an hour later. After the meeting has finished, Sarah pulls back her MRACell and sets it to red (private). For the body of this vignette, please refer to appendix 11.2.3.c.

##### **Analysis**

Overall this vignette is an example of a an individual using somebody else's MRACell but it also provides details about people making themselves aware of the state of the MRA and aligning the MRA to stay aware of coming events. Finally, the arrangement of a document exchange shows how multiple channels of communication co-exist.

##### *Using somebody else's MRACell*

The meeting has been scheduled in the C9 MRACell, usually inhabited by Beatrice, Gemma and Sam. It has been arranged for one o'clock, so that it at least partly overlaps with the lunch time at Nottingham. Therefore, the majority of this meeting is conducted with Karl having the C9 MRACell for himself.

When the permanent inhabitants do come back, there is only a brief interruption (lines 62 – 73), before Sarah and Karl continue. Shortly after, Sam leaves to work elsewhere in the building and Beatrice leaves for the day (panel 13:08:12). The meeting itself continues only for a further 90 seconds. From this vignette, it appears that this potential clash between uses of C9 does not cause major problems.

### *Making yourself aware*

At the start of this vignette, Karl re-configures MRA by moving the MRL MRACell through the virtual environment (panel 12:53:15). He is one of the three people who have agreed to meet in MRA. He turns the MRACell towards the existing group of C9 and Bath, moves towards them, past them and turns around again to face them from the other direction. Although he pauses several times, he does not make any attempts to make contact with Sarah, who is working in her office. No audio is transmitted between the two MRACells. However the recording makes clear that from at least two positions en route Karl would have seen directly into Sarah's office. Right at the outset but also later where he pauses briefly, Karl would have seen Sarah sitting at her desk in the Bath MRACell. Equally, at the end of the re-configuration, the view out of the MRL MRACell would have allowed Karl to see that the C9 MRACell is open and possibly vacant, as the door was closed.

It appears that Karl very purposefully explored the MRA to be aware of its state, of the presence of the remote partner Sarah for the upcoming meeting and of the availability of the C9 MRACell, where the meeting has been arranged. He follows this by walking upstairs and entering C9 to commence the meeting.

### *Being aware of things to come*

As one of the previous vignettes has shown (see Vignette 3) the MRA was pre-configured by Sam, so that the C9 MRACell was in easy reach of the Bath MRACell. In the absence of Sam, Sarah has strengthened the link by moving even closer to C9. She closely monitors events in the C9 MRACell, anticipating the meeting that has been scheduled for one o'clock. Karl knocks on the door of C9. When he knocks again, Sarah looks up (panel 12:55:55). After he has entered, it is she who starts the conversation (line 1).

What is shown here is that Sarah has re-configured the MRA so that she can be aware of events in another MRACell that are about to happen. She very much anticipates the meeting to start and is in fact in the middle of answering one of Karl's emails regarding the meeting (lines 3 and 5 - 6).

### *Documents*

Karl has prepared some graphs detailing results from one of his studies. He brings paper copies to the C9 MRACell, which he refers to during the discussion

(line 34). Karl and Sarah discuss the exchange of these for further discussion (lines 39 and 105 – 109).

Although MRA does not provide a facility for document exchange, this does not appear to cause any problem. For such exchanges inhabitants switch to other channels, like email for example. These channels exist side by side with MRA.

#### **8.1.2.e Vignette 5 – Joining an existing group**

Date	Start time	Duration
30/07/2004	15:33:23	8 min 44 sec

##### **Context**

This vignette shows Scott (SA) joining but also breaking up an existing group of MRACells when initiating a conversation with Sam (SH). The conversation lasts for several minutes. Scott and Sam talk about the MRA privacy settings and how they have been transgressed, about paper reviewing and some technical issues before breaking up the meeting. Shortly after Scott re-links the C9 and 127C MRACells to discuss an additional technical issue before breaking up a final time at the end of the conversation. For the body of this vignette, please refer to appendix 11.2.3.d.

##### **Analysis**

This vignette allows the analysis of three aspects of MRA. It demonstrates how multiple interactions can take place within the same MRA and how inhabitants manage these, it demonstrates how the MRA topology is shaped by inhabitant's requirements in terms of social interaction and finally it shows how differing perceptions of social etiquette can lead to differences between inhabitants.

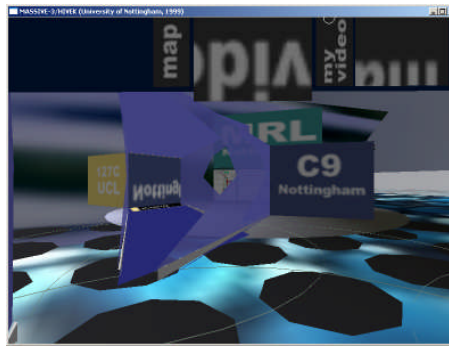
##### *Multiple interactions*

The interaction described here demonstrates how multiple events are taking place in MRA at the same time and illustrates different ways for managing these. The main interaction is between Scott and Sam over the MRLink between the C9 and the 127C MRACells. Four other interactions overlap with this and will be considered below.

Firstly, just before the main conversation, Sam and Gemma talk very briefly in the C9 MRACell. While still talking to Gemma, Sam already re-configures the MRA to be able to interact with Scott (lines 4-9), who he can see approaching in the background. The conversation between Sam and Gemma goes over seam-

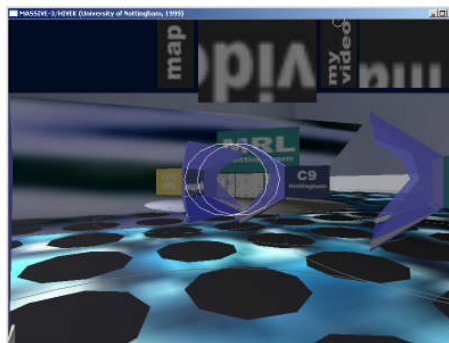
lessly into the interaction between Sam and Scott. In this instance, one conversation has given way to another. They are separated in time.

Secondly, when this interaction commences, Kate is working at her desk in C54. She rotates her MRACell around in the direction of that interaction (panel 15:34:54). From her view point it would have been clear that the meeting does not concern her, as the other two cells were brought up close to each other.



**Figure 62 View from C54 15:34:55**

She pulls back her MRACell to outside the audio range and continues with her activity in the office. Through the movement in virtual space she has separated the two activities spatially from each other.



**Figure 63 View from C54 at 15:35:07**

Thirdly, shortly after the conversation between Sam and Scott has started, Gemma, also in C9, starts a conversation on the office phone. She moves the phone over to her desk, sits back down and dials (panel 15:34:54). The conversation lasts until after the conversation between Sam and Scott has finished. Two different links, the MRLink and the phone, to two different remote physical spaces from the same local space exist at the same time and are being maintained for a considerable period parallel to each other. Because both interface technologies are fixed in physical space, the two interactions cannot be separated

spatially. Of course, if the communication had been initiated from a mobile phone, this would have been different.

Finally, Richard waits for a meeting with Maria to commence in the MRL meeting area. At this point, the MRL MRACell is still in audio range of C9 and 127C. As pre-emptive measure, to make the meeting more private in the MRL, Richard moves the MRL MRACell away from the other two. In planning ahead, he separates the two MRACells in virtual space and therefore the activities taking place within them.

What the above demonstrates, is that multiple interactions can and do overlap within MRA and that these do concern a variety of people in different places. Social interaction can take place in the same physical space as shown in the first and fourth examples. It can take place between two or more remote physical spaces linked by MRA, as demonstrated in the main interaction between Scott and Sam. Finally, social interaction can take place between two or more remote physical spaces that are linked by another technology located inside one of the MRACells, as shown in the third example. This technology can be spatially fixed (e.g. the office phone) but could also be mobile (e.g. mobile phone)

These multiple interactions do not necessarily interfere with each other but when they do, inhabitants employ different strategies to resolve this. In all cases, interactions can be separated in time, by making them consecutive rather than run in parallel (see example one). Activities taking place inside a specific MRACell can be separated from activities taking place in another by increasing the virtual distance between them (see examples two and four). Finally, two activities taking place in the physical part of the same MRACell can be separated in physical space, if one of the activities can be moved to outside the MRACell. This depends on whether the interaction is physical only (people can be moved elsewhere) or uses some communication technology. In case of the latter, separation of interaction depends on whether this technology can be moved. Here the office phone cannot be moved and two interactions continue at the same time within the C9 MRACell.

#### *Architectural topology as result of social interaction*

At the outset of this vignette, the three open MRACells are arranged in a tight triangle, facing inwards and each other (see panel 15:33:44). This configuration

has persisted for just over 30 minutes before the start of this vignette. During this period there was no interaction across the three MRACells, although they were in audio range. As the three are arranged so tightly, a fourth MRACell can only get into good visual contact with one or more of them, if the configuration is broken up or at least re-arranged. At this point this could have resulted in at least two principal topologies. The first one is a group of four, with the C9, C54, MRL and 127C MRACells being arranged in a square. The second one is a group of two with other groups re-forming or other MRACells remaining separate.

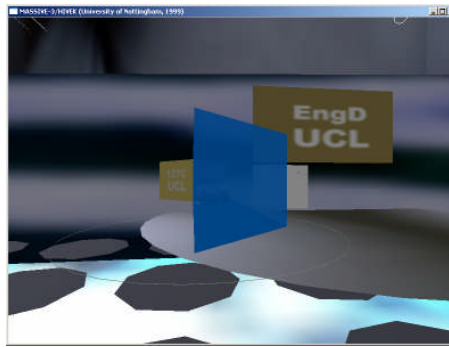
Here, the topological outcome is guided by the intention of Scott wanting to speak with Sam and to a lesser extent Sam's movement of the C9 MRACell in reaction. When Scott approaches, Sam moves the C9 MRACell around, back and then towards the 127C MRACell (panel 15:34:54). The main interaction takes place between those two MRACells. The C54 and MRL MRACells are moved as a reaction, to avoid audio spilling over (panels 15:35:07 and 15:37:08).

This demonstrates how the overall architectural topology is a direct outcome and reflection of inhabitants' requirements in terms of social interaction. This vignette shows two reasons for topological re-configurations, which can also overlap. Firstly, MRA is re-configured quite purposefully, with a specific aim, which is mostly to enable social interaction between two physical spaces. Secondly, Sam's movement can be described as aimed at establishing social interaction with Scott, but also as a reaction to the new topology as established by Scott. Finally, Kate and Richard do, when they pull back their MRACells as response to the new topology.

The overall effect can be seen when comparing the initial MRA topology (panel 15:33:23) with the topology at the end of this series of interactions (panel 15:42:07). A relatively regular triangular arrangement of three open MRACells, which took some time to be established, has given way to a scattered arrangement of four open MRACells.

### *Transgressing privacy*

At an earlier stage (not shown in this vignette), Peter, a relative newcomer to MRA, had ignored the privacy requirements indicated by Scott. Scott had set his MRACell to yellow (semi-private). This makes the video stream appear opaque for others looking at the MRACell in virtual space as shown in Figure 64 below.



**Figure 64 127C MRACell in semi-private state**

This state was designed to indicate to others that somebody is actually present within the MRACell concerned but that they might be busy and might not want to be disturbed. Scott understands it that way (lines 13-30). When meeting students earlier (not shown in this vignette), he sets it to yellow and therefore appears to expect that nobody would approach from virtual space. He complains that Peter ‘was trying to invade a meeting’ (line 14) and that he ‘came charging through’ (line 16). Sam speculates that Peter might not know yet what the different privacy settings are designed to indicate (line 25). In turn, when commenting on this event, it also emerged that Peter was unaware that MRA has a, if not very explicit, feature that allows inhabitants to ‘knock’ on somebody’s door. As the audio nimbus extends beyond the geometry that represents the different privacy settings, audio is transmitted before two MRACells overlap their core geometries, allowing calls across to ask, if somebody might be available although their MRACell is set to semi-private or private. Knocking on a physical surface works equally well. Here two expectations about the system clash. Scott, the more experienced inhabitant, has internalised how to express his contact and privacy requirements with the use of the settings provided. He expects that others respect those and expresses his irritations when they don’t. In turn, Peter might not have learned about the privacy settings yet or might choose to ignore them for whatever reason, which causes the friction shown in this vignette.

#### **8.1.2.f Vignette 6 – Collaborative Exploration**

Date	Start time	Duration
30/07/2004	16:00:41	8 min 12 sec

##### **Context**

This vignette shows the collaborative exploration of the MRA by Fred (FM) and Sarah (SD). Their actions lead to two encounters at two of the MRACells and two

attempted encounters at the other two MRACells, where either nobody is available for interaction or those available are not directly approached.

Fred and Sarah open their MRACell, move over to the C9 MRACell where they have a conversation with Gemma (GA). They then navigate to the MRL MRACell where two people are just leaving. After moving to the C54 MRACell they have a conversation with Kate (KB). They then approach the 127C MRACell, where nobody appears in camera view. Fred and Sarah then move back close to their starting position and close their MRACell. For the body of this vignette, please refer to appendix 11.2.3.e.

### **Analysis**

This vignette illustrates two aspects of MRA. On the one hand, it describes the extent to which an understanding that people might have of connected physical spaces, influences social interaction with people in those spaces. On the other hand, it describes how two people can collaborate when exploring MRA.

#### *Known topologies and people*

Both Fred and Sarah used to work in Nottingham and are aware of certain aspects of the spatial topology and know a substantial number of people working there. They are also aware of the relation between spatial topology and people at Nottingham, as they generally know who to expect where. The material presented in this vignette shows how this awareness can become a resource for making decisions about who to contact where and when. The following considers the four ‘visits’ by Sarah and Fred to other MRACells during this vignette.

The first stop in their exploration of the MRA is the C9 MRACell (lines 1 – 22). As they arrive, nobody is in camera view but Sarah suggests that Sam cannot be far as the door is wide open (line 2). However she is also aware that there might be another reason for this (line 4). Other people usually located in this office are Xenia and Gemma, whose desks are just outside the view of the camera. Both might be expected to be present when entering the C9 MRACell. Although nobody is in camera view at the beginning, Sarah and Fred persist. They wait around, calling out a second time, until Gemma reacts, moves into camera view and a conversation is initiated (line 6). This shows how they use their existing knowledge of the Nottingham space and the people located there in their attempts to enter into a conversation with Sam. This knowledge is used to overcome the fact that nobody



appears in camera view at the outset of the interaction, which would often stop people even from approaching close enough for an audio connection.

The next stage of their exploration is the public MRL MRACell. Apart from C54, this is the only other MRACell in this building. If Sam is not present in C9 and likely to be elsewhere in the building, there is a chance that he can be reached there. When Sarah and Fred arrive, two people can be seen walking through the MRACell on their way out (lines 24 – 28). However, those people are not recognised by Sarah and Fred (lines 26 – 27). They do not attempt to enter into a conversation with them. Glenda's voice can be heard coming from her office, which is in camera view but cannot be looked into. From material not included in this vignette, it is clear that she is talking to Sam. However his voice is inaudible at that point and the recording does not allow any judgement about whether Sarah and Fred might have been aware of this interaction, which is physically very close by.

What they are aware of is that there is a meeting going on in the MRL outside the camera FoV and Sarah suggests moving away so as not to disturb this (line 32). So here Sarah and Fred show a very clear understanding of the topology (e.g. they move there as alternative to C9, they remark on people just moving through) and a sense of current activities in that space (e.g. the meeting going on). However, they do not recognise the only people who actually appear in camera view while they are looking. Also, these people do not stop; they are on their way to somewhere else. As they cannot see anyone they know and are aware that they might disturb others, they do not persist with entering into a conversation but instead move away.

At the next stop, Sarah and Fred pass by the C54 MRACell and enter into a conversation with Kate (lines 34 – 120). Here the topology of the physical environment of C54 must be assumed to be very clear to both. Fred used to be located in the office next door when he was working in Nottingham, and Kate is a former colleague, well-known to both. When they arrive, Kate is sitting at her desk in what is a single office. No other person can be expected to be found here apart from visitors. A conversation starts involving all three. For this interaction the topology of the space, as well as the person in camera view, is well known to Fred as well as Sarah. There is also no potential confusion with areas that might

be out of the FoV of the camera. Kate would have been visible at her desk from a distance away and a conversation starts immediately, without hesitation.

Finally, the last stop of this tour of four MRACells is the 127C MRACell at the CS department at UCL (lines 121-127). The topology of this space is unknown to the two. On request, both reported that they had never been to the physical space itself and do not know where other people they know at CS-UCL are located in relation to 127C. However, both know Scott, the sole occupier of 127C very well. He is a colleague on a shared project.

When they arrive at 127C, nobody is in the view of the camera. The view into this space also does not reveal whether the only door to this space is open or not. Sarah remarks that Scott might be just round the corner (line 127), but there is no way of telling or being sure. It is likely that the door was left open at this point in time as Scott had only left about 30 seconds earlier (see panel 16:07:41). However this fact and who might or might not be available outside Scott's office cannot be seen on the camera view and from what they say, when questioned, is unknown to them. Very much unlike the first interaction in this vignette, Sarah and Fred do not persist by for example calling several times to see whether anyone might make themselves available, or whether Scott is really just round the corner. So here the person to be expected in 127C is well known to both parties but the topology of this space is not. They cannot make any judgments about who they might be able to reach and they do not persist.

Considered together, the material presented here shows that inhabitants use a number of different resources when making decisions about who to contact where and under what circumstances. These resources are used to gain an understanding of the remote setting, which includes the setting's topology, the people to be expected there and the relationship between topology and people. Breaking this down further, it can be argued that when making decisions about the initiation of social interaction, people make use of their:

- Pre-existing knowledge of the physical topology at the remote site (e.g. there is a meeting room just round the corner; the office of X is just next door).

- Information about the topology at the remote site that can be gathered from making the connection (e.g. there is a meeting taking place at this moment; X is in because the lights are on)
- Pre-existing knowledge of people at the remote site (e.g. the work habits of colleagues or friends)
- Information about people that can actually be gathered from making the connection (e.g. is the person known to somebody connecting actually present in the MRACell)

The pre-existing knowledge about topology and people tends to derive from previous visits to the physical spaces connected, but might of course also have been accumulated over time when using MRA. Gathering information about a physical site through MRA is usually done in two parallel ways: through the technology and through conversations. In the first instance, the video and audio transmits certain pieces of information to a connected site. However, conversations with people are just as, or even more effective, especially when people do not appear where they are expected to be. Only through the information gathered from others can a person then be found, as the camera and microphone only reach a very short distance into physical space. Combining pre-existing information with that gathered through a connection allows inhabitants to make very detailed judgements about the appropriateness of initiating social interactions at the different MRACells as has been shown in this vignette.

Some generalisations can be made here although of course it is not suggested that these could describe every interaction taking place within MRA. Knowing the circumstances of a remote space and the people inhabiting that space, in combination with a known person appearing in camera view, facilitates the initiation of social interaction. In contrast, this vignette and material from other vignettes shows that when a person does not know the remote space well, and no known person appears in camera view, social interaction is very unlikely to be initiated.

### *Exploring MRA together*

One notable aspect of the interactions described above is that the exploration is done collaboratively by Sarah and her partner Fred, who is a visitor to 4.9 on this particular day. His workplace is at a different university in a different city.

It appears that Fred is attempting to get into contact with Sam from the outset. He can later be heard talking about trying to find him to discuss arrangements for an upcoming conference in Nottingham. This is also where he takes the 4.9 MRACell first, although Sarah suggests stopping by at Kate's. After turning on the projector, Sarah hands Fred the joystick. He has clearly some difficulties with getting started, especially when trying to open the MRACell. However, Fred remains in control of the joystick during the whole episode and appears to have no difficulties with the use of the joystick itself or with navigation later on. Sarah makes two suggestions for people to visit that are both ignored at first by Fred (lines 23 and 33). At a later stage during this interaction both of those are visited.

The joystick interface to MRA does not necessarily lend itself to collaborating directly in the use of the system. Only one person can be in control of the joystick and of where the MRACell is ultimately taken and of course there is only one viewpoint into the virtual space for each MRACell. In this example, navigation as such is controlled entirely by Fred.

However, in terms of initiating the interaction at the MRACells visited, it is Sarah who takes the lead. She starts both conversations, with Gemma and Kate (lines 1 and 36) and alerts both that Fred is present, as he is a visitor and could not normally be expected there. Sarah is the main inhabitant and others in MRA would expect to see her when the 4.9 MRACell is close by. She also attempts to speak to Scott (line 121) and decides that it might not be appropriate to disturb people in the MRL (line 32). Both arguably have a similar knowledge of the physical spaces visited including their topology and people located there, but Sarah has got much more experience in using MRA.

Although there is only one interface to each MRACell, the exploration in MRA consists of a number of different but interconnected activities and this makes collaboration during exploration possible. It needs to be decided where an MRACell is moved to, whether and how a conversation is initiated, in addition to the work going into dealing with the actual interface itself.

To make this collaboration possible, people need to have a suitable view of the screen that MRA is projected on to. As 4.9 is very small, Sarah and Fred align themselves at the edge of the screen (see video stills) during the entire vignette, and because camera and projector are set up directly opposite of each other,

stepping into the centre of the camera FoV would mean occluding parts of the image on screen. Even though this provides them with a good view and access to the interface, others are provided with a view that shows only parts of both people at the very edge of the video frame (see Figure 46)

#### **8.1.2.g Vignette 7 – Finding someone in the MRA topology**

Date	Start time	Duration
29/10/2004	15:12:58	12 min 34 sec

##### **Context**

This vignette describes four interactions taking place within MRA, interwoven with other events. All four are the result of someone attempting to find another inhabitant of MRA.

Firstly, Eric (ES) enters the C9 MRACell physically and attempts to find one of its inhabitants, most possibly Sam. Gemma (GA) tells them that the person is elsewhere in the building. Secondly, Sarah (SD) reconfigures MRA by placing her own MRACell close to the C9MRACell, where she is trying to get in contact with Sam (SH). Gemma tells her that Sam is elsewhere in the building. The conversation between Sarah and Gemma that follows covers the possible weekend use of MRA. Thirdly, Sarah reconfigures MRA again by moving her own MRACell closer to the MRL MRACell. Another attempt to locate Sam at first fails, but succeeds, when Sam physically passes through the MRL MRACell, by coincidence. A conversation between Sam and Sarah follows, covering the re-location of the MRACell and privacy issues. Finally, this conversation is briefly interrupted by a chance encounter at the MRL MRACell, when Maria and Sarah have a short chat about an upcoming paper submission. For the body of this vignette, please refer to appendix 11.2.3.f.

##### **Analysis**

This vignette allows the detailed description of a number of aspects of MRA. They are the initiation of social interaction, the relationship between MRA topology and the topology of the connected spaces, the two distinct groups of people living in MRA, issues of privacy and dealing with technical audio problems.

### *Initiating social interaction*

This vignette shows two different ways for inhabitants of MRA to establish social interaction with another inhabitant: intentional encounters and unintentional or chance encounters. These occur side by side, are often intertwined or a result of each other. What follows is an outline of the five encounters described in this vignette.

Eric physically enters the C9 MRACell in Nottingham to locate one of its inhabitants (lines 1-3). When entering, he meets Gemma who is another inhabitant of that same MRACell instead of the person originally sought. This chance encounter is the direct result of the attempt to interact with somebody else. It can only be assumed that this is indeed a very typical occurrence in any office setting.

In a very similar way, a chance encounter results from the attempt by Sarah to locate Sam in C9 (lines 4-82). By re-configuring the MRA she places her MRACell close to the C9 MRACell and attempts to talk to Sam, who is normally located there. Compared to the previous interaction, Sarah approaches the same architectural entity in a very similar way, just from the other side, topologically speaking. Although no one appears in camera view, Sarah persists, possibly because she knows that the camera FoV does not cover the whole physical space. Her calling out into this space results in another chance encounter involving Gemma who is still located in the C9 MRACell. Gemma tells Sarah that Sam is located elsewhere in the building and this is followed by a conversation about other things.

After this failed attempt to establish social interaction with Sam in C9, Sarah does find him at the MRL MRACell, which is physically the nearest MRACell to where Gemma said Sam might be located (lines 83-329). Although this time the encounter is intended, its establishment is somewhat more complex as Sam does not hear Sarah calling for him, but wanders through the MRL MRACell by coincidence. Seeing Sarah pull back her MRACell, Sam follows, which makes this social interaction intended by Sarah but established by both.

Finally, two chance encounters occur during the conversation between Sarah and Sam that are established independently of the intended encounter taking place there (lines 133-156). Marcus approaches the screen, looks on for a while, but he is not involved in any dialogue. Directly following this, Maria approaches and is

involved in a discussion with Sarah about a paper they are working on together, while Sam is looking on for a while (158-215).

### *Interwoven topologies*

The sequence of events described above also shows that the topology of MRA and the topologies of the buildings it connects are tightly interwoven in everyday use. Transitions between these two topologies appear to be seamless to people living in MRA.

At this point, it might be worth reiterating the relationship between those two topologies. The MRA topology comprises one shared virtual space and a number of physical spaces. For all practical purposes it only reaches into those physical spaces in a short, narrowly defined way: as far and wide as the camera can see, the screen can be seen and the audio can be transmitted to and from. This means that although it does connect remote physical spaces, only a small part of each connected physical space becomes part of the MRA topology. The remainder of the connected physical spaces are therefore only part of the general overall spatial topology of physical reality, or more concretely of the actual building that MRA has been constructed within.

What the vignette shows is that people are frequently moving in and out of the MRA topology and it demonstrates how this physical movement impacts on social interaction. When Eric enters C9 (line 1), when Gerald passes through the MRL MRACell, when Marcus remains in view of the MRL MRACell camera for while (lines 133-134) or when Maria talks with Sarah there (159-214), they have entered MRA topology, which makes them available for interaction to others who are connected. So simply by moving around physically in their local environment, people cross into and out of the topology of MRA, making use of both topologies for social interaction.

However, whether they can actually initiate such social interaction with someone in a remote space depends on how MRA has been configured at that particular moment, and this re-configuration is largely dependent on the core users or long-term inhabitants of MRA.

The process of re-configuration can demonstrate the relationship of the two topologies from a different angle. A good example is when Sarah exploits the flexibility of MRA as she is trying to find Sam. She makes use of her knowledge

of the building topology in Nottingham, in combination with the information she received about the whereabouts of Sam, to re-configure the MRA topology. By locating her MRACell first near the C9 MRACell and then near the MRL MRACell, she achieves a similar effect to physically walking between the two, albeit taking a different route (compare virtual positions of the 1.2a MRACell (lines 4 – 329)). For her the MRA topology in combination with the building topology at Nottingham becomes a resource that allows her to be aware of the activities of people based in that building. She is able to get into contact with Sam, who at first is located outside the MRA topology but then enters it, which leads to an extended conversation between the two. Sarah also understands that Glenda is not available as the lights are turned off in her office (lines 95 – 98). Glenda's office is not part of the MRA topology but just outside it and visible in the camera view of the MRL MRACell.

Of course, Sarah's re-configuration of MRA, like any re-configuration by any other inhabitant, has an indirect effect that most probably goes unnoticed during use. Just like physical architecture, MRA structures patterns of co-presence, as this vignette powerfully demonstrates. In contrast to physical architecture, this structuring effect within MRA takes on a dynamic form, directly resulting from the interaction of inhabitants. Only because Sarah and Sam have placed the 1.2a and the MRL MRACell close to each other, can a chance encounter between Sarah and Maria take place. If such closeness between two or more MRACells does not exist, chance encounters cannot occur between people traversing the MRA topology physically. Then they can only result, if one party takes the initiative: encounters become intentional.

### *People in MRA*

The material presented in this vignette also clearly shows that there are two broad types of users of MRA who are differentiated by their access to and control over MRA: inhabitants and visitors.

Inhabitants are the people who have regular prolonged access to an MRACell. Although their experience with MRA varies, as result of the staggered introduction into the different spaces and their own interest in using MRA, it is based on at least a number of months of exposure. Usually their office or at least their main work space (as for example in a lab area) is part of an MRACell itself. This applies to Sarah, who is doing most of the navigation here, and also to Sam as well



as Gemma, who do some mostly ‘corrective’ navigation in response to Sarah placing her MRACell.

Visitors generally have much less direct experience with MRA and have little control over its configuration. They are only visiting, as their main office space is located elsewhere in physical space. This applies to Eric coming into C9 to find one of its inhabitants, Marcus observing an interaction in the MRL MRACell, Gerald simply passing through that same cell and Maria being involved in a discussion with Sarah. Their use of MRA becomes opportunistic and is mostly organised around the pre-existing topological structure as set by the inhabitants. This is not to say that visitors can not re-configure MRA. The public MRL MRACell for example can be moved with the joystick that is prominently located in front of it. However, the material presented here and in other vignettes shows that re-configurations by visitors are rare.

In summary, what is shown here is that inhabitants of MRA take control of the MRA topology, actively re-configuring it according to their needs. This then impacts directly on the possible chance encounters within MRA, between and among the different groups of people using MRA.

### *Privacy*

The vignette also shows two different situations where privacy is a concern and how people deal with those situations. In the conversation with Sam, Sarah mentions that one person, a dissertation student of Sarah, refuses to enter her office because of the presence of the MRACell installation (lines 128-158). The student asks to be met outside the office to discuss paper work and work in progress. This could be a reaction to MRA being set up in that room or more directly to the recording taking place, as the student was being alerted to that by Sarah. Although invited, this person refuses to become a visitor in the 1.2a MRACell and therefore the MRA topology. She does not make herself available to others who are connected over the system remotely but also changes the way Sarah uses MRA by asking her to leave the MRA topology with her for the requested meeting.

A different concern arises caused by the fact that MRA is being recorded at this particular moment and during the conversation it becomes clear that Sarah is very aware of that fact. She decides to wait before phoning her bank so that bank

details will not appear on tape (lines 249 – 252 and 282 – 325). She is concerned that although the tapes are only with Sam, somebody else might get hold of them. Sam expresses his understanding, attempts to re-assure Sarah that the data is safe but also suggests to ‘pull the plug’ for instances like that. However, Sarah decides to simply wait until the recording is finished.

Sarah is also concerned about some information that has already been recorded. She asks Sam to take out, or at least not use in a presentations, some material appearing on tape. It is agreed to discuss this offline, i.e. not on the system or the recording. Here it becomes clear that the fact that recording is taking place has a clear effect on Sarah’s use of MRA. The inhabitant waits for recording to finish to discuss confidential information. At the same time this suggests that she does not have the same problem when MRA is operational but not being recorded.

#### *Audio problems*

It appears that there are technical problems with the audio quality at the MRL MRACell caused by inappropriate settings of the echo canceller. Audio transmitted from the MRL is partly cut off and Sarah asks Sam as well as Maria a number of times to repeat things. First, this happens during the initial conversation with Sam, a long-term inhabitant of MRA. He moves closer to the screen and microphone and the problem appears to be overcome (line 122). When Maria joins the conversation, the problem reoccurs. Sarah has difficulties understanding (e.g. lines 175 and 221). Sam prompts Maria to get a bit closer to the screen, which improves the situation.

Although this problem occurs and reoccurs the dialogue shows that the conversation does not actually break down. The repositioning closer to the screen makes a noticeable difference but some problems persist and certain parts of the conversation remain unclear, but this is repaired collaboratively at a later stage. Sarah prompts Sam to repeat a key part of the conversation between her and Maria, which also confirms that she did actually understand partly in the first instance.

### 8.1.2.h Vignette 8 – The Birthday Cake

Date	Start time	Duration
19/10/2004	14:51:10	10 min 42 sec

#### **Context**

It is Thomas's (TA) birthday at the Bartlett MRACell and someone has brought in a cake to celebrate the occasion. Thomas re-configures the MRA to have a 'virtual birthday', while not explicitly telling others in the MRA. After a brief 'happy birthday' song by Fran (FC), Michael (MC), Christian (CD), Serena (SO) and Collin (CB), the cake is distributed. Collin and Michael decide to 'show' the cake (very large in camera view) to the 'recording' and to Sam (SH) at the open MRACell of C9. Although Samir (SW) is present there, no conversation results from this interaction. Collin and Michael then decide to move on to visit the MRACell, where they show the cake again. Rick (RL), who is just passing through, also is not involved in a conversation. For the body of this vignette, please refer to appendix 11.2.3.g.

#### **Analysis**

Before and during the birthday celebrations, a number of attempts are made to draw in others currently present in MRA. This is likely to be in response to Sarah previously having an event at the Bath MRACell that also involved a cake (not recorded as a vignette). Firstly, Thomas reconfigures MRA so that the C9, MRL and Bartlett MRACells form a tight triangle and suggests having a virtual birthday party (line 10). No one is in camera view in the MRL. Sam is in camera view in C9 and Samir is also present but cannot be seen. Thomas makes no attempt to call out, to establish contact with anyone in these spaces, but Sam appears to be aware of the arrival of the Bartlett MRACell. Secondly, Fran and Thomas joke about showing the virtual cake to Sam in the C9 MRACell, but again no contact is attempted with people either in C9 or in the MRL (lines 11 to 12). Thirdly, Michael and Collin hold a slice of cake into the camera and move the MRACell very close to the C9 MRACell. By this time Sam has left C9 and Samir remains outside the camera view. Michael acknowledges that Sam is not present and that the recording is running (line 37). No further attempts are made to establish contact with C9. Finally, the MRA is re-configured again so that the Bartlett is close up towards the MRL MRACell. When Rich walks past there, he would have seen a piece of cake filling the projection screen but no people to establish contact with.

Again, Michael and Collin do not address Rick directly as he is passing and no interaction is established.

What this shows is that although a number of (half-hearted) attempts are made to establish interaction with people in MRACells other than the Bartlett, the main event, Thomas's birthday, is essentially local, taking place for the benefit of the people at the Bartlett MRACell. Most of the other inhabitants in MRA do not know Thomas personally and he does not know them. His birthday will be celebrated whether MRA is installed or not and whether others are available or not. This interpretation is supported by the fact that a large amount of the interaction during the birthday party is between people located within the Bartlett MRACell. The conversation is not directed at the MRA installation as it is not intended for people connected and this also makes it difficult to transcribe.

Showing the 'virtual cake' to Sam and the recording becomes a local joke around which much of the interaction evolves. Interestingly, this local interaction does result in a series of reconfigurations (panels 14:51:35, 15:01:28 and 15:01:45) of MRA that seem to have mainly one purpose: to feed back into the local interaction. Here the overall architectural topology can be shown to be an effect of interaction mainly concentrated in a single MRACell.

At the same time this vignette might well hint at the potential of MRA for cultural transmission. A cake was part of an event that Sarah held at the Bath MRACell only a few days earlier. During this event her cake was clearly subject of discussions between inhabitants, especially of course the fact that nobody outside Bath would be able to taste it. Nevertheless, it provided inhabitants with an occasion that could be shared across physical spaces. It is likely that Thomas was prompted by this previous event to celebrate his birthday around the MRA interface. Although the people involved in Thomas's birthday celebrations were not core users, this vignette hints at the fact that MRA can provide quite rich awareness of other spaces and the equipment for social reproduction.

## ***8.2 Log Data Statistics***

The long-term recording of MASSIVE3 system logs not only supported the observational study as described above, but also allowed a statistical analysis of use. As stated previously, system logs were recorded during the normal opera-

tion of MRA in parallel to the video recording. However, the data set extends beyond the video material and covers a number of periods of varying lengths from 14 separate days between 22 July and 29 October 2004. The overall set was then filtered in two ways. Only data falling between the hours of 9:30 and 18:30 was used in the analysis as only during these hours could any interaction with MRA be expected. Furthermore, only time spans during which all six MRACells were present in the MASSIVE3 scene graph were considered, which eliminated all periods where one of the client processes had crashed. The above resulted in a log covering just less than 94 hours.

Any MASSIVE3 recording consists of the recorded changes to a known starting state over time. To analyse this, the data set needed to be checkpointed to produce data sets for specified time periods. A sampling time of under ten seconds was chosen, which seemed small enough not to miss any relevant events. The checkpointed data allowed the analysis of the relative positions, orientations and privacy settings of all six MRACells. The entire data set amounted to over 64000 sets of position, orientation and privacy settings for each of the MRACells. What follows is a brief excerpt from such a data set.

Unix Time	MRACell	X	Z	Y	Rot	Priv
1099145527	Bartlett, UCL, London, UK	7	0	57	-29	1
1099145527	C54, Mixed Reality Lab, Nottingham, UK	-52	0	34	102	2
1099145527	MRL, Mixed Reality Lab, Nottingham, UK	-35	0	5	174	2
1099145527	127C, EngD, UCL, London, UK	-45	0	-18	150	0
1099145527	C9, Mixed Reality Lab, Nottingham, UK	-14	0	32	-64	0
1099145527	Psychology, Bath, UK	-39	0	62	26	0
1099145538	Bartlett, UCL, London, UK	7	0	57	-29	1
1099145538	C54, Mixed Reality Lab, Nottingham, UK	-52	0	34	102	2
1099145538	MRL, Mixed Reality Lab, Nottingham, UK	-35	0	5	174	2
1099145538	127C, EngD, UCL, London, UK	-45	0	-18	150	0
1099145538	C9, Mixed Reality Lab, Nottingham, UK	-14	0	32	-64	0
1099145538	Psychology, Bath, UK	-39	0	62	26	0
1099145548	Bartlett, UCL, London, UK	7	0	57	-29	1
1099145548	C54, Mixed Reality Lab, Nottingham, UK	-52	0	34	102	2
1099145548	MRL, Mixed Reality Lab, Nottingham, UK	-35	0	5	174	2
1099145548	127C, EngD, UCL, London, UK	-45	0	-18	150	0
1099145548	C9, Mixed Reality Lab, Nottingham, UK	-14	0	32	-64	0
1099145548	Psychology, Bath, UK	-39	0	62	26	0

**Table 14 Excerpt of data log**

This data was then filtered further by separating out data for the individual MRACells. An example of such a data set follows. It represents an excerpt of about 2 minutes of the activity of the Bath MRACell as recorded on the 29<sup>th</sup> of October 2004. The first column of the table below contains the date and time in Unix

seconds, which is then translated into BST in column two. The name of the MRACell follows with its X and Y position, global orientation and privacy setting recorded in columns 4 – 7.

Unix Time	Date / Time	MRACell	X	Y	Rot	Priv
1099145527	29/10/2004 14:12:07	Psychology, Bath, UK	-39	62	26	0
1099145538	29/10/2004 14:12:18	Psychology, Bath, UK	-39	62	26	0
1099145548	29/10/2004 14:12:28	Psychology, Bath, UK	-39	62	26	0
1099145559	29/10/2004 14:12:39	Psychology, Bath, UK	-39	62	26	0
1099145569	29/10/2004 14:12:49	Psychology, Bath, UK	-39	62	26	0
1099145579	29/10/2004 14:12:59	Psychology, Bath, UK	-39	62	26	0
1099145589	29/10/2004 14:13:09	Psychology, Bath, UK	-39	62	26	2
1099145599	29/10/2004 14:13:19	Psychology, Bath, UK	-33	49	26	2
1099145609	29/10/2004 14:13:29	Psychology, Bath, UK	-25	34	26	2
1099145619	29/10/2004 14:13:39	Psychology, Bath, UK	-15	31	168	2
1099145629	29/10/2004 14:13:49	Psychology, Bath, UK	-16	28	127	2
1099145639	29/10/2004 14:13:59	Psychology, Bath, UK	-15	29	127	2
1099145649	29/10/2004 14:14:09	Psychology, Bath, UK	-15	29	127	2
1099145659	29/10/2004 14:14:19	Psychology, Bath, UK	-15	29	127	2
1099145669	29/10/2004 14:14:29	Psychology, Bath, UK	-15	29	127	2
1099145679	29/10/2004 14:14:39	Psychology, Bath, UK	-15	29	127	2

**Table 15 Excerpt of data log**

What the above excerpt can show is that at 14:13:09 the Bath MRACell was opened. It was then moved and rotated by approximately 100 degrees to the right. In its entirety the data set then allows certain comparative statements to be made about the use of MRA, which will be discussed below.

### 8.2.1 Movement

The data set allows the study of the rates of movement of all the different MRACells. What is of interest here is how these rates compare to each other rather than the total distances travelled. Therefore and for simplicity, the changes in recorded X and Y positions were summed up respectively, before totalling the results. The C9 MRACell showed the highest rate of movement and the movement rates of the other MRACells were therefore expressed as a proportion of its rate. The table below summarises the results.

MRACell	C9	MRL	Bath	Bartlett	C54	127C
% (rounded)	100	56	26	16	13	7

**Graph 14 Rates of Movement**

The rates of movement vary widely. The C9 MRACell (that of the author) covered the greatest distance, nearly twice as much as the next highest entry.

However, this figure has to be treated with care as the C9 MRACell was used for testing as well as actual use by the author. The least active MRACell in terms of movement was the 127C MRACell, with 14 times less movement than C9 and still only about half the rate of movement of C54, the second lowest entry.

### 8.2.2 Privacy settings

It is then worth looking at the privacy settings over the entire period. The state of the privacy settings that people have chosen for their MRACell provides information about how much they made themselves available to others in MRA for interaction. Only when an MRACell is set to open, are video and audio from there fully available. When set to semi-open, the video is only visible to others once they enter the virtual cell of any of the MRACells, which requires them to be very close. Once an MRACell is set to closed, video is unavailable. The audio transmission is not affected by the privacy settings. The table summarises the findings.

	127C	Bartlett	C54	C9	MRL	Bath
<i>Closed</i>	65.22	46.01	46.07	21.96	21.60	77.35
<i>Semi</i>	2.95	3.48	4.12	4.26	0.04	0.13
<i>Open</i>	31.84	50.51	49.81	73.78	78.36	22.52

**Table 16 Privacy settings in % of total time**

The C9 and MRL MRACells were both open most, around 75% of the overall time period. During the time period represented here, the privacy settings for the C9 MRACell and the MRL MRACell were both controlled by the author, while in terms of movement only the C9 MRACell was under the author's control. This is simply a result of the MRL MRACell being installed in a public space where the author turned it on and off every day. In contrast, the Bartlett and C54 MRACells were both open for about 50% of the total time, while the 127C MRACell was open for around 30% of the time and the Bath MRACell only for about 20%. The latter two were therefore available to others for the least amount of time.

The table can also show that the semi-open state was used very little. It was designed to allow people to indicate that they were in the physical part of their MRACell but did not want to be disturbed. This did not appear to be regarded as very useful by inhabitants.

### 8.2.3 Pairs

Finally, spatial relationships between clients can be examined from this data. Although all spatial relationships between all clients could potentially be examined, it was decided to concentrate on those that would enable visual and verbal communication. This was the case for all MRACells that were open, within the field of view of at least one other MRACell and within audio range, which was set to 20 virtual metres during the study

As the audio level gradually increases, when the 20m threshold is passed, audio communication is practically possible only at about 16m. This value was set for the analysis. In addition to this, the vignettes have already shown that people did not really talk when at very steep angles to each other and therefore the FOV that was investigated was reduced to 70°. This also takes account of possible differences in local audio settings, and ensures that at this setting there is real potential for visual and verbal communication, regardless of whether communication was actually taking place.

Through the inspection of the data, it also became clear that there were many instances where MRACells were arranged just outside their respective audio ranges but in view of others and set to open. This would allow the maintenance of visual awareness while not permitting verbal communication across the system. A 20m threshold was set and here the full FOV of 84° was relevant as all possible visual connections were of interest. The two tables below summarise the results.

TIME Hours:Mins	127C Bartlett	127C C54	127C C9	127C MRL	127C Bath	Bartlett C54	Bartlett C9
16 m / 70°	1:14	0:00	0:29	0:01	0:02	0:00	0:44
20 m / 84°	1:14	0:00	2:09	0:02	0:02	0:44	2:52

**Table 17 Duration: pair wise spatial relationship**

TIME Hours:Mins	Bartlett MRL	Bartlett Bath	C54 C9	C54 MRL	C54 Bath	C9 MRL	C9 Bath	MRL Bath
16 m / 70°	0:01	0:17	3:55	0:03	0:10	3:22	2:31	0:10
20 m / 84°	7:54	0:56	13:38	0:12	0:11	6:47	2:38	0:12

**Table 18 Duration: pair wise spatial relationship**



The first row in each of the tables lists the pairs of MRACells that are being analysed. The second row lists times in hours and minutes during which this pair was in visual and audio contact. The third row lists times during which pairs were in good visual contact but not in audio contact at the threshold of the MASSIVE3 audio nimbus.

The relationship of the 127C and C9 MRACells might serve as an example here. Out of approximately 94 hours of the total time logged, this pair spent 29 minutes within audio and visual range of each other with their MRACells open, while they spent 2 hours and 9 minutes in visual contact but just outside audio range. The above pattern is repeated for a number of the pairs of MRACells, where the time spent in visual range is considerably higher than that spent in visual and audio range. This seems to indicate that remaining in visual contact with another MRACell is valuable to inhabitants, to be aware generally of activities in the other spaces, since even at a 20m distance certain deductions about others' activities can be made. However, another explanation for this finding could be that it is an artefact of the formality of concluding conversations in MRA. It was very common that inhabitants pulled back with their MRACell at the end of an interaction, usually until they were just out of the audio range of the other party. This left those two MRACells in view of each other, unless one of them travelled further or closed the front, which occurred frequently with the Bath MRACell.

The data also shows large differences in the overall time that pair wise connections were established. The C9 MRACell was connected for the longest periods of time to another MRACell. For example, it was connected to the C54 MRACells for nearly four hours in audio range and for 13 hours and 40 minutes in visual range. As mentioned previously the overall frequency of use of the C9 MRACell was inflated by it being used for testing by the author. However, the data does show that the C9 MRACell was the hub of the MRA environment, most likely as a result of the author having set up the study and therefore everyone knowing him.

Finally, it is also clear that some potential connections were not established or established very rarely. The 127C MRACell can be said not to have been connected to either the C54, MRL or Bath MRACells. The Bath MRACell was only connected to the Bartlett, C54 and MRL MRACell in a way that would have allowed verbal communication for between 10 and 20 minutes. As has already been

shown, the 127C and Bath MRACells were those that were set to open the least often, making themselves unavailable to such connections for ~65% and ~77% of the total time respectively.

#### 8.2.4 Groups

Further investigating the data showed that groups of more than two MRACells were relatively rare. For the definition of groups the same base assumptions were made: MRACells had to be open, see all other members of the group and be at a certain distance from them. The distances chosen were the same as for the pairs above, 16m and 20m, in addition to 26m as the observational study had already shown that when people do arrange MRACells in groups, they do not come very close, allowing them visual access but preventing audio from being transmitted.

First of all, no groups of four or more MRACells were logged that met the criteria outlined above. The count for arrangements of three MRACells then varies according to the distance chosen. The table below summarises the findings.

Distance m	Number	Duration Range min:sec	Duration Total min:sec
≤ 16	1	1:35	1:35
≤ 20	4	1:24 – 9:02	13:46
≤ 26	9	1:24 – 11:25	46:15

**Table 19 Groups of three MRACells**

The data clearly shows that the number of occasions on which three MRACells were in a reciprocal configuration increased with the distance that they were away from each other. The durations also increased. Configurations of three MRACells were therefore rarely used for verbal interaction, but inhabitants did choose to set them up to be visually aware of other spaces. In terms of larger group sizes, it was simply the case that the conditions set out at the beginning were difficult to meet with more than three cells, as a number of people had to have the same aim at the same time. For example, four inhabitants of four different MRACells would have had to decide that they wanted views into the same set of MRACells.

### ***8.3 The collected data***

This chapter has presented the data collected during the main study of MRA. Eight ethnographic vignettes have been introduced that describe in detail what it means to inhabit MRA. They cover a range of topics including the relationship between architectural topology and interaction, the establishment and maintenance of awareness and privacy as well as the motivation for using or not using MRA. In addition to this, the analysis of the log data has allowed a wider and more abstract look at activities within MRA over a longer period of study. What remains is to bring these two strands of data together into a wider discussion of life in MRA.



## Discussion

This chapter discusses the findings presented in chapter 8 from two closely inter-related perspectives, before considering the wider implications of this research for environmental cognition in general Mixed Reality space.

Firstly, the architectural implications of this work are outlined. MRA is a novel architectural concept and it can be described in terms of its configurational properties and the impact of those properties on social interaction. Secondly, life within MRA is discussed in terms of how it is affected by the architectural topology and in terms of how it affects the topology in turn. This is in effect a post-occupancy evaluation of MRA as designed and built for this research. The focus here is not on another iteration in the prototyping cycle, but instead the aim is to provide an in-depth understanding of what it meant to inhabit MRA. Finally, an outline follows of how the different types of access to the main interface technol-

ogy, as it evolved in long term use, has shaped the perception of MRA for the two main groups of inhabitants. Based on these observations, it is argued that environmental cognition needs to consider digital extensions to our bodies and to our environments in its conceptual framework as permanent features.

## 9.1 *A dynamic architectural topology*

At the outset of this research, the topological limitations that exist within physical architecture were introduced and discussed (Steadman, 1983). It was then suggested that MRA can overcome such restrictions, and this was explored extensively during the prototyping phase of this research. For both the major iterations, different types of topology were introduced. For study 1, 'Presenting in Mixed Reality', topological flexibility was very limited. There was only a single change between the two presentations, and this was restricted to the change of a number of virtual and physical elements within the two respective spaces, which resulted in different orientations between the two, as outlined in section 5.1.2. For the second phase, this flexibility was much extended as already described in section 6.4. What follows is a detailed discussion of the effects in terms of architectural adjacency as prerequisite for visibility as well as accessibility and the resulting level of spatial integration as seen in the actual use of MRA.

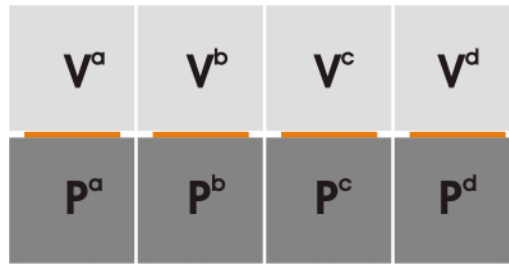
### 9.1.1.a *Topological adjacency*

The following might serve as an example here. Consider physical cells  $P^a$ ,  $P^b$ ,  $P^c$ ,  $P^d$ . For the sake of the argument they are arranged in a line as shown in Figure 65.



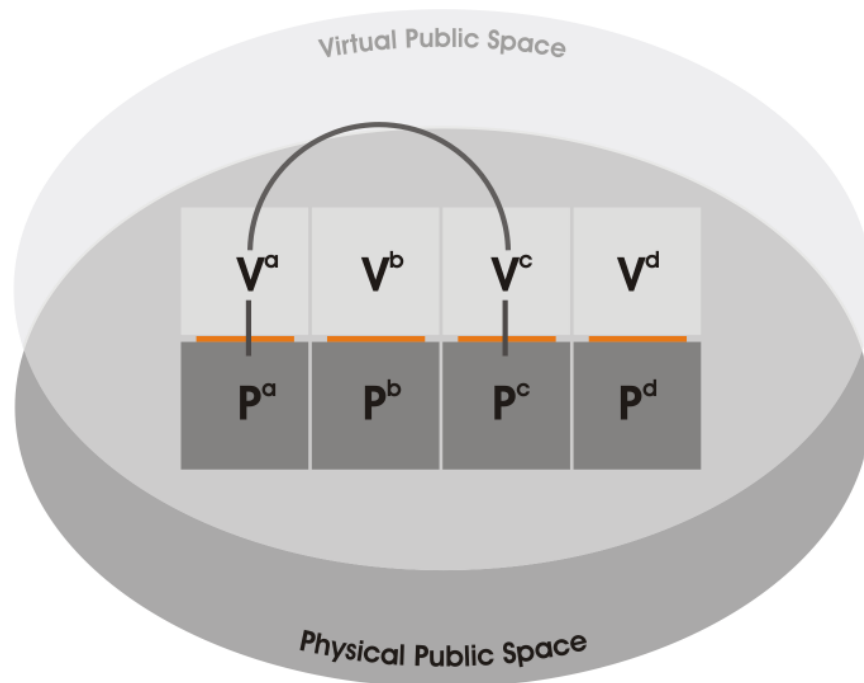
**Figure 65 Four adjacent physical cells**

$P^a$  is adjacent to  $P^b$  which is adjacent to  $P^c$  which is adjacent to  $P^d$ . Clearly, this means that some physical cells cannot be adjacent to certain others. For example, in this arrangement  $P^a$  cannot be physically adjacent to  $P^c$ . The concept of MRACells is core to this research. Here a single virtual cell is permanently attached to each physical cell. They are  $V^a$ ,  $V^b$ ,  $V^c$  and  $V^d$ . The corresponding arrangement of MRACells is shown in the figure below.



**Figure 66 Four MRACells**

Connections across public virtual space can now be made between two or more MRACells as suggested previously. These can be dynamically established as well as ended by inhabitants and a very typical example of this process has been outlined in vignette 1 (section 8.1.2.a).



**Figure 67 Connection between two MRACells**

Through their connection across public virtual space  $P^a$  can now appear adjacent to  $P^c$ , overcoming the geometrical limitations imposed in physical space. Of course this does not change the actual physical arrangement of the two spaces as they both remain in their physical positions. Instead, the resulting configuration might be described as a meta-architectural cell consisting of two physical and two virtual architectural cells. The figure below depicts the same relationship between  $P^a$  and  $P^c$ , concentrating on just the two relevant MRACells.



**Figure 68 Meta-architectural cell**

These can be integrated further by moving the virtual parts of the MRACells closer together, as shown in Figure 69.



**Figure 69 Meta-architectural cell close together**

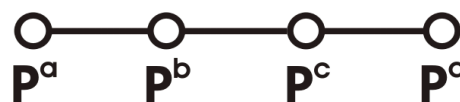
When these are brought even closer, virtual space can effectively be eliminated altogether as shown in the figure below, where MRA is very much like a standard video conferencing system. This demonstrates how the spatiality within virtual space can be adjusted by inhabitants dynamically turning interaction in a shared spatial framework into interaction that is more similar to ordinary video conferencing.



**Figure 70 Meta-architectural cell - physical only**

In all of the three cases above a new functional unit has been established dynamically by inhabitants. This allows inhabitants of the two MRACells to experience co-presence with people located physically at a distance.

A second way of describing this relationship is with adjacency graphs. In this very simple example introduced above, the adjacency graph of the four physical architectural cells looks like the graphic below.



**Figure 71 Four physical cells - Adjacency graph**

This type of representation makes very clear that virtual adjacencies can overcome limits on physical adjacencies as shown in Figure 72. Physically,  $P^a$  and  $P^c$  remain non-adjacent, while virtually they now are.

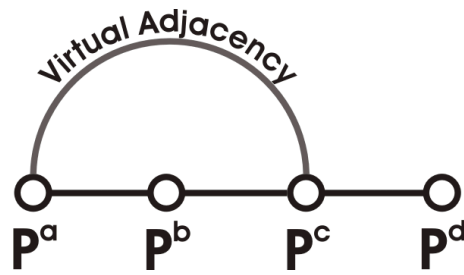


Figure 72 Virtual adjacency

In addition, virtual parts of the adjacency graph can easily change as inhabitants move around with their MRACells and multiple adjacencies can also be established independently from each other, see Figure 73. Vignette 1 shows such an instance when Sam establishes a connection with the Bartlett MRACell while the Bath and C54 MRACells are still connected (see section 8.1.2.a panel 13:35:21)

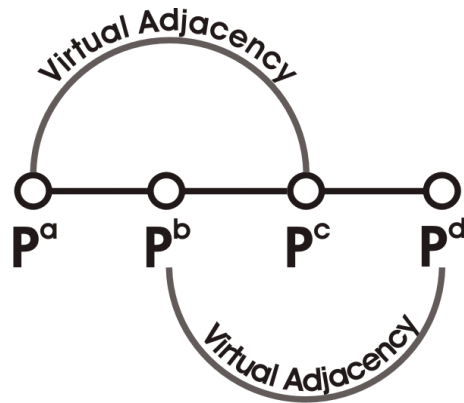


Figure 73 MRACells - Multiple virtual adjacencies

Finally, these considerations also change the perspective on non-planar adjacency graphs as introduced in section 2.1. Non-planar graphs are those that cannot be drawn without some of their edges crossing and are impossible to build as physical architecture on a single plane, as illustrated in detail by March & Steadman (March and Steadman, 1971). Although MRA does of course not change the actual physical plan, it allows non-planar adjacency graphs to be 'built'. Interestingly, as will be shown in section 9.1.1.d, MRA (in its current implementation) introduces its own adjacency limitations.

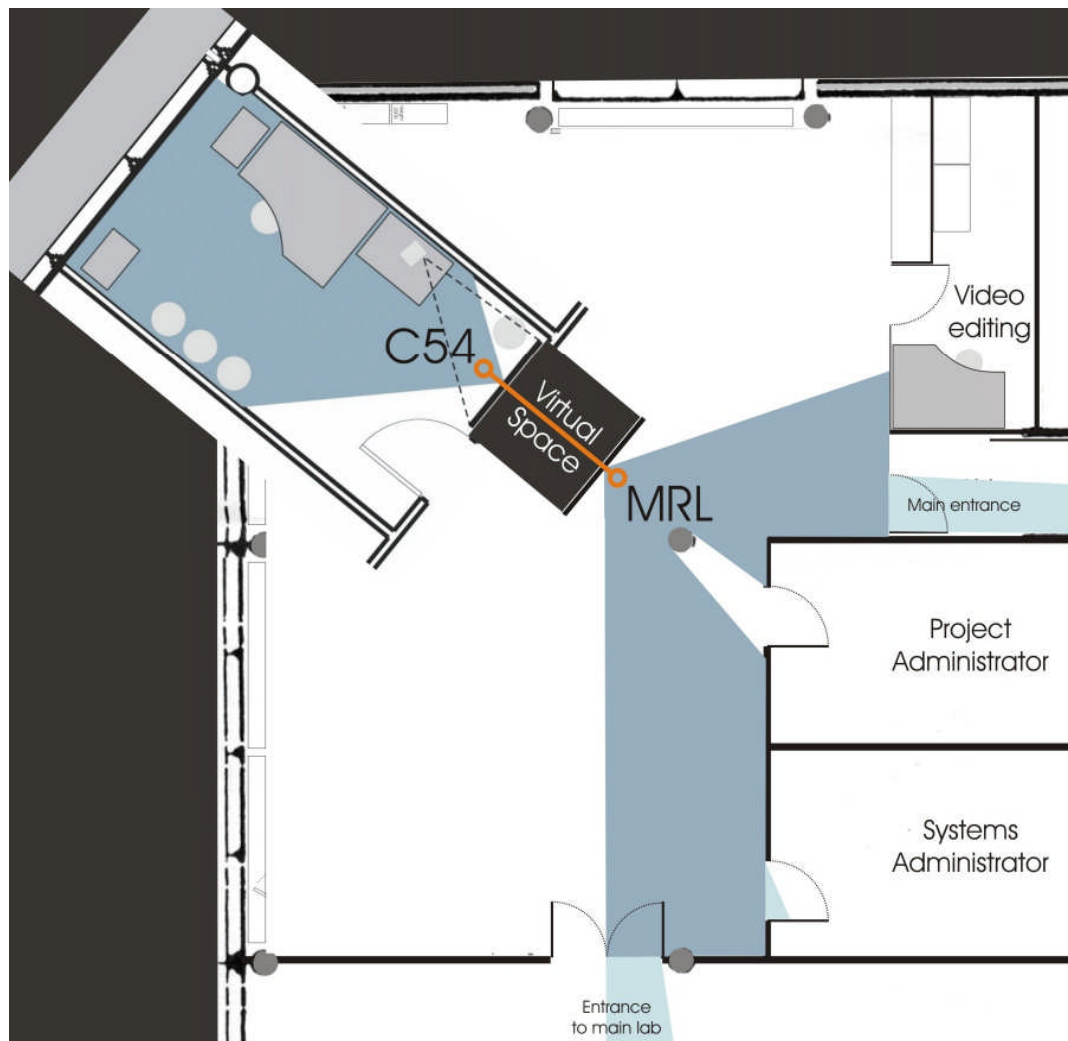
### 9.1.1.b Spatial integration

It is now worth considering the level of integration of a space with the spaces around it and how this changes through MRA connections. Total spatial integration is an expression of the depth of a space from all other spaces in a spatial configuration as outlined in section 2.1.1. As an example, consider the relative in-



tegration of C54 at Nottingham and the MRL foyer as introduced in section 7.2.1. C54 is near the end of a corridor on the second floor of the Computer Science building in Nottingham (see Figure 35).

C54 has already been described as relatively well integrated with its departmental role. It is accessible for students and is well connected to the administrative areas. In relation to the MRL however, as a lecturer's office, it is located on a different corridor from most other MRL offices and on a different floor from the MRL itself, making it deep in relation to those. In contrast, the MRL foyer is central to the MRL as a whole.

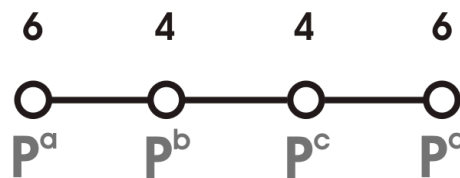


**Figure 74 C54 connected to MRL foyer across MRA**

As can be seen from Figure 29, it is shallow in relation to the main lab space, controlling access to it, two adjacent offices and the video editing suite. It is also more integrated in relation to the remainder of the building, being on the first floor and near the main vertical circulation. When the C54 MRACell is brought

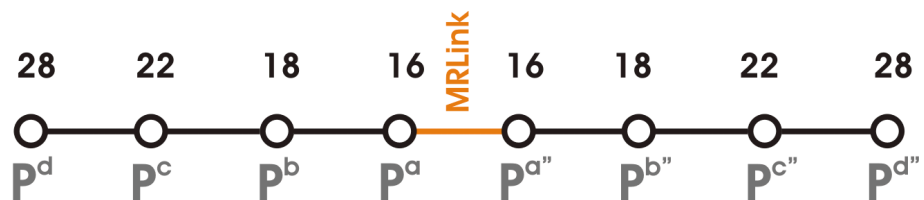
together with the MRL MRACell, its level of integration changes dramatically as can be seen in Figure 74. MRA provides visual and verbal access between the two physically non-adjacent spaces, while of course not allowing actual permeability. However, in terms of visual and verbal access, C54 is now integrated with the core of the MRL lab. One example of how such a change in spatial integration affects social interaction is provided in Vignette 2 (section 8.1.2.b), where a chance encounter results from the close arrangement of two MRACells.

The following two figures express the possibilities in a more general form. This returns to the very simple spatial relationship of the four physical cells  $P^a$ ,  $P^b$ ,  $P^c$ ,  $P^d$ . It is clear that the two central spaces,  $P^b$  and  $P^c$  are more integrated, their integration values as shown at the top of the diagram being lower than those for  $P^a$  and  $P^d$ .



**Figure 75 Spatial integration for four physical cells (including total depth values)**

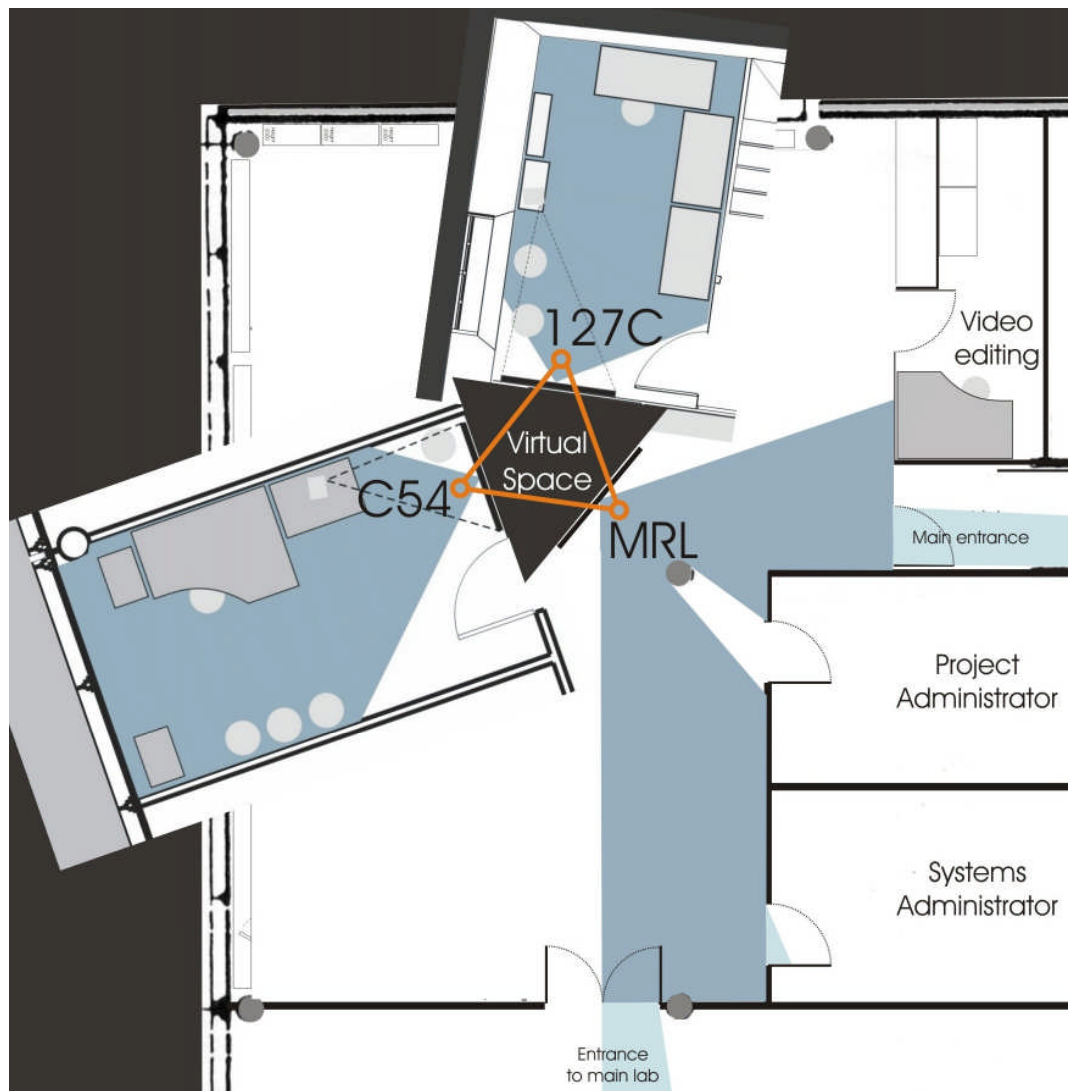
One might then imagine a case where an identical spatial configuration existing in a place remote to the one above is linked across an MRLink. Figure 76 explores this scenario.



**Figure 76 Spatial integration of two sets of four physical cells (including total depth values)**

In contrast to the figure above, spaces  $P^a$  and  $P^a''$  are now the most integrated spaces, if one takes the MRLink into account. So far the discussion has only considered one MRLink being made to a particular physical space. But of course the introduction of the virtual spatial framework allows the simultaneous establishment of multiple connections and these connections are publicly available to everyone close by in physical and virtual public space. In addition to C54 already connecting to the MRL foyer, the 127C MRACell has joined the group. 127C is a lecturer's office at UCL and is located on the first floor of the CS building at UCL

(see Figure 54). As already mentioned it is off the main open plan office, which provides desks for researchers and graduate students. In relation to the remainder of the building it is the deepest space in this part of the building, being located as far as possible away from the entrance. Figure 77 then shows how C54 as well as 127C have both become shallower as a result of the re-configuration that inhabitants have made. In contrast to C54 though, and very importantly in this context, 127C has been made shallower in relation to a physical space whose integration would not normally be considered in relation to 127C, as it is physically too far away.



**Figure 77 C54 and 127C connected to MRL foyer**

There are three additional issues that are worth pointing out here. Firstly, the spatial integration discussed above also extends beyond the actual MRACells to other spaces near by. On the one hand this is simply the result of people actually

moving into an MRACell and then having access to the connection. On the other hand it is the result of the MRA topology extending into other spaces to a certain extent through the placement of the interface technology within physical spaces. This will be discussed in the following section. Secondly, virtual adjacencies cannot reduce the existing level of integration of a particular physical space. Only its level of additional integration through MRA can be controlled through privacy settings and virtual positions by the inhabitants and others. At the same time the physical placement of MRA technology might well have a reductive effect on integration when for example certain types of views and access are blocked as seen in the MRL foyer (see Figure 29) or certain individuals start avoiding spaces as seen in room 4.9 at Bath. Finally, the integration of each separate MRACell is the result of the collective configuration of all MRACells. Although one inhabitant might decide to increase the integration of their MRACell with one or more others, this can easily be changed by other inhabitants moving their own MRACells elsewhere. This results in a dynamic set of integration values for the overall MRA, determined by the individual actions of members of its community.

#### ***9.1.1.c Placement of technology***

When considering the resulting integration of the physical parts of MRACells, a number of other issues were also important. A key issue was where the interface technology was actually installed in each of the MRACells. Their set-up has already been discussed in section 7.4.1. One of the design choices was the central position of the MRB camera on the screen surface pointing away from the screen. When positioning the screen, inhabitants therefore also decided what others could see of their space. In none of the set-ups was the physical cell shown in its entirety, which was simply a result of placing the camera on one of its internal surfaces. However, the aim was to capture as much of the activities as possible. In terms of the orientation of the interface, three relative orientations needed to be considered: the orientation of the interface towards people, the orientation to other interface technologies and the orientation to the access to a particular space.

##### **Orientation towards people**

The orientation that inhabitants chose was often the result of their seating arrangement in the given spaces. In the majority of MRACells someone, if not everyone in the respective connected spaces, was sitting in camera view. For two

MRACells this was not the case. Nobody had their permanent workspace within the physical part of the MRL MRACell. For the Bartlett MRACell, inhabitants deliberately decided to orient the camera in such a way that none of the nine inhabitants' work spaces was within camera view. As the screen orientation was fixed in its location, inhabitants actually rotated the camera on screen so it faced away from the centre. Having no one in camera view then had a detrimental effect for social interaction at that particular MRACell. Other inhabitants connecting across the MRA were presented with an empty video image, suggesting that no one was actually in at all. As Vignette 6 has shown, a number of factors then influenced whether this initial obstacle of not seeing anyone could be overcome. Overall, the recorded material showed clearly that the presence of an empty video view rarely resulted in verbal social interaction. Also, in contrast to the four office MRACells, in the two more public spaces no one was seated in reach of the joystick interface, and this meant that interaction with the interface tended to be slow.

The orientation of the camera in combination with its limited field of view also permitted certain unexpected types of interaction. It was possible to use the interface to MRA while being in camera shot or being outside. As mentioned previously, the MRACells were set up with the aim of covering as much as possible of the physical cell with the installed camera. However, each physical cell had areas that were hidden from view and in all of them it was possible for an inhabitant to use the joystick, view the screen, but remain outside the view of others connected. This frequently happened by accident with newcomers to MRA. For example, they would enter an office like 4.9, be shown the system by Sarah but would not realise that they could not be seen, until it was pointed out to them. The same also occurred deliberately, when people played practical jokes on each other. Clive reported that it was fun to scare people a little by moving an MRACell close to another and calling across, while remaining hidden from view.

### **Orientation towards other interfaces**

The orientation of the MRACell interface to other interfaces in the connected room was also relevant. In all cases where people were constantly in view of the MRA camera (the four office MRACells), the main communication interfaces, like people's desktop computer and the landline phone were also in view. This allowed remote inhabitants to be aware of others communicating with somebody

else over the phone for example. It also allowed an easy handover between different communication channels as seen during phase one (see section 7.3.4.b).

The difference in orientation between the main desktop interface and the MRA interface can provide a further resource for others who connected across MRA (see Vignette 1, section 8.1.2.a). For example, as Kate needed to rotate by about 90 degrees away from her main desktop interface to face and use the MRA screen, others could clearly see which activity she was attending to. Although the angles differed, all installations were set up so that there was a clear difference in rotation very much in contrast to typical desktop video conferencing, where the camera is typically attached above the main computer screen, with the partner in a session displayed below. This type of public availability of the orientation of individuals to different displays or different regions on the same display has previously been noted by Heath & Luff in the context of co-located colleagues in the control room of a public transport system (Heath and Luff, 1992).

### **Orientation towards the environment**

Each MRACell did have at least one physical entrance being the shallow part of its physical cell. Some MRACells had two, such as the MRL and the Bartlett MRACells. The exact placement of the MRA interface technology was a consequence of the discussion with inhabitants as described above. This then resulted in the MRA interface being located and orientated in a particular way in relation to the deep and shallow parts of each space.

Firstly, the location of the MRA interface could be deep, when it was away from the entrance(s) but the camera was pointing at it (them), the shallow part of a space. This was the case for the C9 and MRL MRACells. The vignettes clearly show how inhabitants coming virtually to these spaces used information from the camera pointing to the shallow end of a space as a resource for their decision making. Vignette 6 (see section 8.1.2.f) provides one such example. When Fred and Sarah explored MRA together and arrived at the C9 MRACell, they found the door to the physical cell open and deduced that Sam could not be very far (lines 1-2) and this assumption they discussed with Gemma who was also present in C9 (lines 12-14). A second example is included in Vignette 7 (see section 8.1.2.g), when Sarah discussed the lights in Glenda's office as visible from the MRL MRACell camera. The lights in this building are automatic and the fact that they were off was a good indication that Glenda was out. Sarah discussed this

with Sam (lines 95-97). This placement and orientation also had a direct effect on people coming physically to these spaces as the screen was clearly visible from the shallow end of the physical cell. In the case of the C9 MRACell, the screen could be seen from just outside C9 on the corridor and the audio tended to project to this space as well. For example, this allowed Bill to effortlessly join a conversation between Sam and Sarah, since he had seen and heard it taking place when he walked past C9.

As a result of the placement of the MRA interface technology the space itself was then also transformed, as a formerly deep part of a space was converted into a shallow part, from where other inhabitants of MRA would enter to interact socially. For the C9 MRACell for example this would therefore mean that it became more like a corridor, with control over the access to this corridor granted to the inhabitants of C9. Vignette 7 provides an example. Gemma in the C9 MRACell first interacted with Eric entering via the physical shallow end of the room before turning around shortly afterwards to interact with Sarah entering via the virtual shallow end (see section 8.1.2.g).

Secondly, a very similar situation is exemplified by the Bartlett MRACell, where the shallow end of the physical space is large enough to hold both entrances. Here the location of the screen-camera combination was shallow and faced one of the entrances, the other shallow end of the space.

Thirdly, the MRA interface could be shallow itself, when it was near the entrance, with the camera pointing towards the deep end of the space. This was the case for the C54, A11, and 127C MRACells. People connecting to these spaces across MRA were provided with very little sense of the topological context of the MRACell in its physical surroundings. At the same time, people passing by physically were not provided with any sense of the state of the MRA as the screen was turned away from the entrance. On request, Kate confirmed that no interaction between a person physically passing by and person connected over MRA had occurred by chance at the C54 MRACell, where the interface was facing the deep end of the physical space. The effect on the space itself was much less dramatic than with the first category. The MRA installation merely re-enforced the 'shallowness' of the entrance area and did not affect the deep part of the space.

Finally, there were also installations where neither of the above was the case. Here the installation was located somewhere in between deep and shallow ends and pointed at neither of them. This was the case with the 4.9 and 1.2a MRACells at Bath, where the size and shape of the room meant that the only available surfaces large enough to hold the projections were on the long sides of the spaces. Here no topological context was transmitted to people connecting over MRA, because this was not in camera view, while people passing by physically might have been able to see the MRA interface depending on its angle to the door. What the installations did do was create a second shallow area in a physical space at an angle to the physical shallow end.

What can be said in summary is that there were clear interactional consequences at least for the two main types of installation. Installing the MRA interface near the deep part of a physical space and pointing it at the shallow end encouraged chance encounters between people passing by and people connecting over MRA. It also turned this space into a corridor between physical topology and MRA topology and the access via two shallow ends now had to be controlled by inhabitants. Doing the opposite, installing the MRA interface in the shallow part and pointing it at the deep part had much less dramatic effects. Both access points to the physical part of the MRACell in question were then located at the same shallow end.

#### *9.1.1.d Virtual topology*

So far topological arrangements and relationships have only been considered within physical space. Although the physical architectural topology has been made more flexible, other topological limitations have been introduced in virtual space as Figure 77 clearly shows. These limitations are defined by the possible distances between MRACells and their relative angles in virtual space, resulting in a limit on the maximum number of MRACells that can be arranged so that they remain aware of each other. Figure 74 shows that two MRACells, when arranged head on, both have a good view of the other's video. For three MRACells the situation changes as shown in Figure 77. Arranged as they are in a triangle still allows them to get good views of each other. The angle between each pair is not too steep and the virtual distance can be kept small to allow them all to be in



audio range. If one of them rotates, it will affect what others can see of it. If one of them pulls in too close, it may well block the others' views.

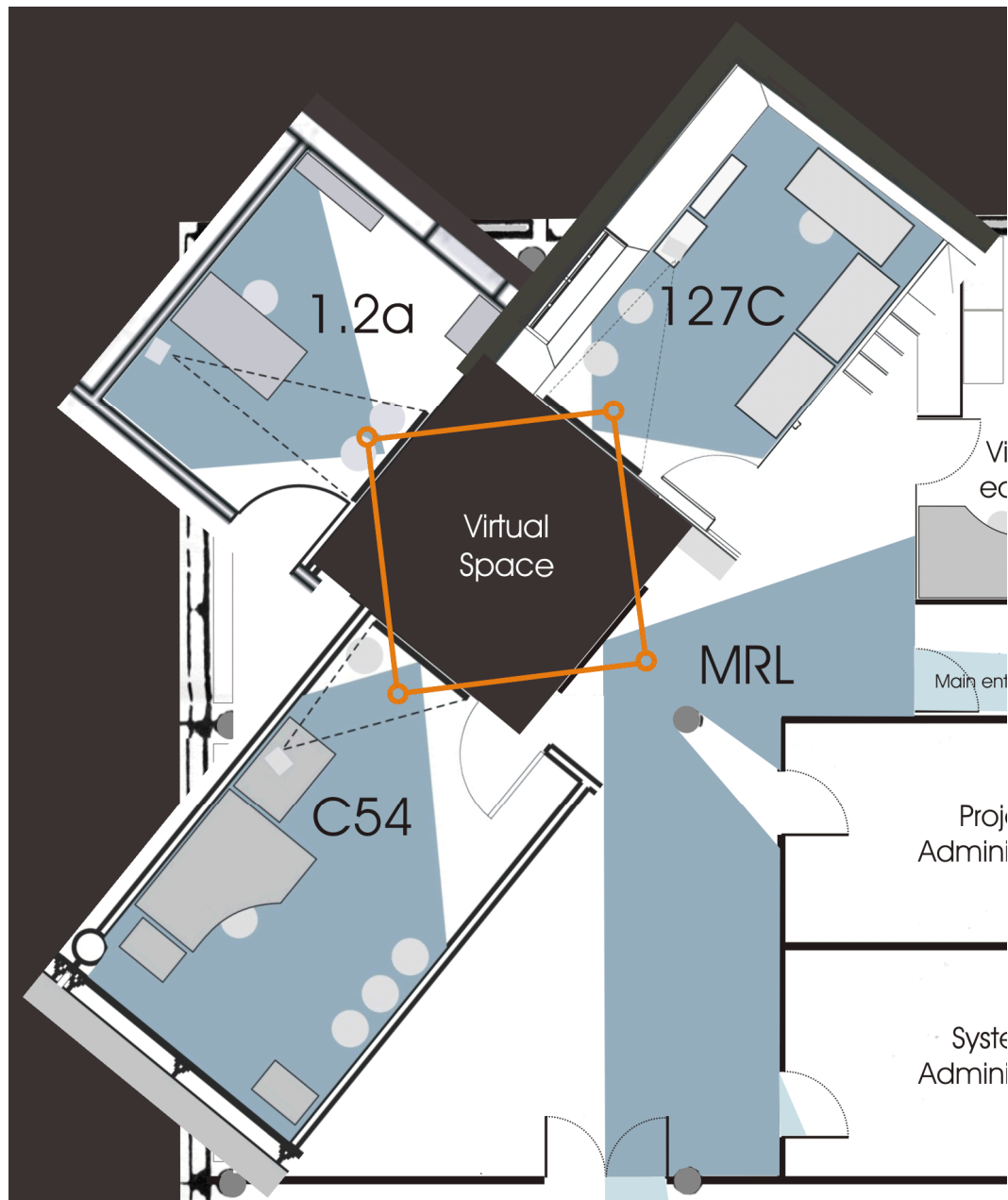


Figure 78 C54, 127C and 1.a connected to MRL foyer

This demonstrates how the maximum number of clients in a single virtual configuration is clearly limited. With four clients, any two adjacent video views are already at 90 degrees to each other as shown in Figure 78. Increasing the number above this would not only push the angle too high but would require an increase in distance, which at some point means that the group could not stay in audio range of each other. This is also reflected in the logs which show that arrange-

ments of three were relatively rare and there were no instances of groups of four or more recorded, at least not at shorter distances (see section 8.2.4).

One might also speculate about the promise of increasing possible group sizes by making use of the third dimension of the public virtual space. For example, a group of six MRACells could be established without increasing viewing angles or distances by arranging them on the faces of a cube, looking inwards. To provide consistent views to all, some of the videos would then have to be rotated in different directions for different inhabitants so that all would see all others the right way up at all times. Another step would be to distort virtual space from the perspective of each inhabitant so that all others could be arranged in view. Conventional video conferencing then goes a step further, as it does not provide any spatial framework at all (Jancke, et al, 2000). However, not only are those alternatives ultimately limited by available screen space, they are very likely to lead to problems with spatial referencing during social interaction, which have been discussed in section 2.3.1.a in relation to media spaces.

Besides geometrical constraints, one reason for the rarity of group arrangements was the independence of each of the MRACells to position themselves within the virtual topology. Vignette 5 shows how a group of three was broken up by a fourth MRACell. When Scott moved his MRACell close to the C9 MRACell, the latter was already arranged in a triangle with the MRL and C54 MRACells. Sam reacted to Scott's arrival by rotating towards him and breaking away from the configuration. In turn, the C54 and MRL MRACells were pulled back to avoid audio being transmitted. This shows how a situation that could have resulted in a configuration of four produced the dispersal of an existing configuration of three instead, as Scott's intention was to speak to Sam and therefore no attempt was made to organise the overall configuration with the other inhabitants.

Therefore, one needs to be careful in attributing the rarity of groups larger than two to geometrical effects alone, as there were likely to be other reasons for this. There were only six MRACells altogether. Getting larger groups together was therefore relatively unlikely in itself. It also appeared that with six MRACells connected, groups of people who wanted to talk about the same thing were limited in their numbers. Of course multiple groups could be established in different regions of the virtual environment and this was not limited by geometry, while it would have been limited by the overall size of the environment.

### ***9.1.1.e A novel type of architectural interface***

In section 2.1.2 different types and levels of change in architecture have already been discussed and the framework in section 3 has introduced the level of topological change theoretically possible in MRA. The following briefly discusses change as experienced in MRA. For study 1, Presenting in Mixed Reality, the topological change was very limited. The two spaces linked over the single MRB were permanently connected. The change was restricted to elements within the space itself, similar to moving partitions or furniture within a room; and this was controlled by the system rather than by inhabitants. These limits to topological change were due to the programmatic nature of the event supported by this event. It was scheduled and followed a certain set of rules or 'long model' as outlined in section 5.3.

For study 2, Mixed Reality Architecture, this was very different. Here topological change was designed to be fundamental. The virtual sites of spaces changed and through this the relationship to other spaces was also adapted. This change was entirely controlled by the inhabitants themselves. This is in contrast to Brand's analysis, who argued that inhabitants have very little control over the actual site of the physical buildings that they occupy (Brand, 1994). It is also very different to Price's proposal for the Generator project (Price, 2003). Although Price did allow for the sites of spatial units to change, this was controlled by a computer.

However, they did not control any of the other MRACells and there was also no centralised control over the overall topology of MRA, as has already been mentioned. There were no overall rules that would influence or determine what the overall structure of MRA should be, beyond the overall size of the virtual space and the fact that there were only two vertical levels in this space. In that respect MRA might be described as a very rapid and changeable manifestation of the processes that Hillier & Hanson outlined when discussing the agglomeration of physical architectural cells (Hillier and Hanson, 1984). Just as with physical architecture, in MRA this process is restricted by the rules and norms of the society inhabiting it, the community of MRA inhabitants. For MRA these rules were partly derived from experience in physical space but also emerged from long-term inhabitation. The following are a few examples of such unspoken rules. Lurking, staying in audio range without being seen, was not acceptable and no

instance of this behaviour was recorded. Inhabitants also generally avoided each other's MRACells when navigating. There were no recorded instances where two or more MRACells occupied the same virtual space for any length of time. Also breaking through somebody's closed 'front door' was deemed unacceptable and Vignette 5 includes a discussion where Scott stated that he thought this behaviour to be inappropriate (see section 8.1.2.e). What appeared to be perfectly acceptable though was to stay in sight of others but out of audio range. This allowed inhabitants of that MRACell to be aware of other physical settings visually but not listen in on them. Indeed, this separation between visual and aural awareness in MRA and the communal legibility of the state of the two was a very important feature.

These rules then influenced the overall configuration of MRA. Taken together these behaviours frequently resulted in virtual architectural configurations that were widely spaced so that visual awareness could be maintained. The log data has clearly shown that the number of group formations increased with the distance of group members from each other (see section 8.2.4). Although there were a number of recorded instances when close proximity was maintained between MRACells for longer periods, this was mostly for times when verbal social interaction was actually taking place and was between just two MRACells (see section 8.2.3).

Seen in this context, the MRACell as developed for this research, can be described as entirely new architectural interface. Architectural interfaces are spatial manifestations of social relationships. The interfaces between inhabitants and strangers as seen in the elementary architectural cell has been described by Hillier & Hanson (see section 2.1.1) (Hillier and Hanson, 1984). The MRACell has extended this notion in three ways. Firstly, it is an architectural interface between local and remote spaces, which allows people from both of these spaces to interact socially. Secondly it is spatially mobile which allows spatial relations to be adapted by participants on the fly in a way that is legible by others. Finally, spatial relationships between the different MRACells in MRA are not limited beyond their starting positions (there are no planning laws), while they are clearly limited in terms of geometry. In that sense MRA, as introduced in study 2, might be described as following the 'shortest model' possible. This is in contrast to study 1 (see chapter 5), whose design was spatially more rigid and where the activity that

was supported followed a ‘long model’ (compare section 5.3). In contrast, study 2 in a similar way to a party ‘maximises the randomness of encounters through spatial proximity and movement’ (Hillier, 1996) although this spatial proximity is now virtual. Such an interface is not possible in entirely physical architecture as its constituent parts are too inflexible. Certainly, other remote communication technologies, especially shared online environments, had similar aims in terms of supporting chance interaction between people that are remote to each other. The review in section 2.3.1.b provided an overview. However these cannot be described as architectural interfaces. In contrast, some of the video technologies that support remote social interaction described in section 2.3.1.a are interfaces that are architectural in a similar way to MRA due to their size. But as the remote connections are not embedded in a common spatial framework in this case, the interface itself is spatially fixed.

## ***9.2 Inhabiting MRA***

The rules and norms that allowed and produced certain architectural topologies have been discussed in the previous section. The emphasis of this section is then on inhabitants’ motivations to produce these topologies and their motivations for interaction within those. With the aim of providing a description of what it means to inhabit MRA, the material gathered in vignettes and through observations by the author has been brought together with direct feedback from inhabitants, material collected in diaries and the log data statistics. Firstly, inhabitants are described in terms of the groups they belong to, their roles, collaboration between them and their relationship to the MRACell that they interact within. Secondly, the motivations of inhabitants to interact within MRA are outlined, including sections on awareness, social interaction and privacy, before the social network of MRA is considered. Finally, a reflection follows on the relationship between social interaction and dynamic architectural topology.

### **9.2.1 Inhabitants**

As one of the design decisions for MRA resulted in the emphasis on connecting spaces rather than individuals over MRA, the group of inhabitants was relatively large. The observational study has shown that inhabitants of MRA fall into very similar categories to those that Hillier describes ( see section 2.1.1) according to

their status, which is differentiated by access to and control over MRA: core inhabitants, permanent inhabitants and visitors. These will be now discussed in turn.

### **Core inhabitants**

A core inhabitant was that person for each MRACell who had the most contact with MRA. This was easy to define for the private offices C54, 4.9/1.2a and 127C where Kate, Sarah and Scott were the sole occupants and therefore the main users of the respective MRACell. A core inhabitant also existed for the shared C9 MRACell. The author himself was the main user of the MRA technology in C9, although others were also permanently located there.

### **Permanent inhabitants**

A second group consisted of those people whose main work space was in one of the MRACells, but who were not the main users of MRA. This applied to a rather large group of people whose membership changed over time as people moved in and out of the MRA topology. For example, in a shared office like C9, this applied to Gemma who used the MRA occasionally but was not the main user. This category also applied to people in the more public spaces. In case of the Bartlett MRACells, there were nine people located permanently inside the physical part of the MRACell, with a number of others located in the surrounding offices, who did also occasionally make use of MRA. The MRL MRACell did not have permanent inhabitants and the people in the adjoining offices did not take up using the interface. Neither of the two had core inhabitants who used the MRA frequently.

Both the above groups of inhabitants had regular prolonged access to at least one MRACell in principle. Although their experience with MRA varied, as result of the staggered introduction into the different spaces and their own interest in using MRA, it was based on a number of months of exposure at a minimum.

### **Visitors**

The final category comprised all visitors to the MRA topology, simply meaning that their work space was not located in an MRACell. Sometimes visitors were located very close by, as for example next door to one of the MRACells. In this case, they could have gathered some experience with MRA over time. Other visitors might only come into contact with MRA once during a visit to one of the labs and they would not have gained any experience with MRA themselves but in-

stead would have been shown around by others. Interestingly, the control over whether strangers become visitors or intruders takes place away from MRA. The various physical building fabrics that the MRA topology was embedded in had that function: all of the MRACells were installed relatively deeply in their respective physical sites. To reach these spaces the existing thresholds between outside public spaces and more private office corridors had to be traversed.

#### **9.2.1.a Roles of different groups**

These three different groups exerted very different levels of control over the topology of MRA. Vignette 7 (see section 8.1.2.g) can serve as an example here. It details four interactions taking place within MRA, interwoven with other events. All four are the result of someone attempting to find another inhabitant of MRA.

During the interaction, the core inhabitant Sarah did most of the re-configuration of the topology as she was trying to speak to Sam. The core inhabitant Sam and the permanent inhabitant Gemma mostly reacted to the initiative taken by Sarah but also directly influenced the MRA topology themselves. In contrast, the visitors involved in this series of interactions took no direct role in navigation. This applies to Eric coming into C9 to find one of its inhabitants, Marcus observing an interaction in the MRL MRACell, Gerald simply passing through that same cell and Maria being involved in a discussion with Sarah. The visitors' use of MRA was opportunistic and was mostly organised around the pre-existing topological structure as set by inhabitants. This is not to say that visitors could not re-configure MRA. The public MRL MRACell for example could be moved with the joystick that was prominently located in front of it. However, the material presented here and in other vignettes showed that re-configurations by visitors were comparatively rare.

In summary, it can be said that inhabitants of MRA took control of the MRA topology, actively re-configuring it according to their needs. This then impacted directly on the possible encounters within MRA, between and among the different groups of people using MRA.

#### **9.2.1.b Collaboration**

The interface to the MRACells was designed to be used by a single person. Joysticks are difficult to share and are in themselves designed for single use. In fact,

the majority of interaction with MRA occurred in this way as the vignettes have already shown (Vignettes 1 and 2 are good examples. See sections 8.1.2.a and 8.1.2.b).

Of course this did not mean that others could not participate in interaction. If the set-up in a particular MRACell permitted, several people could quite easily gather around the interface as the screen itself was certainly large enough. From this viewpoint, others would watch but frequently also participate in conversations taking place. For example, during Vignette 7 Maria joined an extended conversation between Sam and Sarah at the MRL MRACell (see section 8.1.2.g). In most instances however, this did not translate into participation with the re-configuration of the MRA topology itself. It tended to be slightly more passive.

However, there were occasions when more than one person took control over decisions about where a particular MRACell might be moved. One example has already been introduced with Vignette 5 (see section 8.1.2.e). Although Michael actually navigated, Collin indirectly participated in where the Bartlett MRACell was to be placed. Vignette 6 then provides a very clear example of how collaboration can be achieved (see section 8.1.2.f). Fred, a visitor to the Bath MRACell, aimed to get in contact with Sam at the C9 MRACell. Sarah, the core inhabitant of that MRACell, was part of the entire interaction that developed from this. What is shown is that MRA allows such collaborative explorations and interactions without major problems. Fred and Sarah shared decisions on where the Bath MRACell might be moved and whether and how conversations were initiated, while the actual navigation itself in terms of dealing with the joystick remained in Fred's hands.

### ***9.2.1.c Relationship to MRACell interacted within***

What the above also shows is that interaction with MRA did not always occur from within an MRACell that the inhabitant concerned owned. Three principal relationships between the person interacting and the MRACell that they were interacting with could be distinguished.

Firstly, they could be the owner of a particular MRACell, which might be said to be the case for people who were core and permanent inhabitants. They would have had an extended experience with the use of MRA and, as has already been mentioned, it was core and permanent inhabitants who did most of the re-



configuration of MRA. Especially when placed in a single office, their interactions did not usually interfere with others' activities in the same space. Secondly, people interacting with an MRACell might have done so at a public MRACell which had no clear core or permanent inhabitants. Depending on where this space was, it might well have led to conflicts between activities, as people did not have sole control over the space. Informal feedback from inhabitants of the Bartlett MRACell suggested that the use of the interface there did indeed cause interruptions to other activities. Finally, people did occasionally use somebody else's MRACell, a case which is illustrated by Vignette 4 (see section 8.1.2.d). Karl used the C9 MRACell for one of three arranged meetings with Sarah at the Bath MRACell. C9 was 'borrowed' from its inhabitants for this purpose for a specific time, when people were likely to be at lunch. As they returned, the meeting continued for a while, seemingly without causing significant problems. However it was clear that situations like this would probably not be sustainable for longer periods, because they would simply be too disruptive for the actual inhabitants.

### 9.2.2 Motivations

Two different overall reasons for re-configuring MRA could be identified. Inhabitants re-configured it purposefully according to their needs and requirements and this then often triggered others to react to the new situation by reactive re-configurations. This behaviour was indeed very common: Vignette 5 provides a good example (section 8.1.2.e). When Scott re-configured MRA to be able to speak to Sam he approached a group of three MRACells. As there was no virtual space for him to join the group, Sam broke away. This was on the one hand a purposeful re-configuration to enable social interaction with Scott, but it was also a reaction to Scott's actions. Finally, Kate and Richard reacted to the new situation by pulling their MRACells back from the new group, so they were not disturbed themselves by the audio streaming from these locations. In discussing this point, Kate stated that it was also to provide privacy for others' conversations.

Beyond this more general point, the material collected for the observational study provides detailed information about people's motivation for using MRA. This will be discussed in the following sections covering awareness, social interaction

across MRA, privacy issues, the re-configuration of MRA for others, the use of MRA as demonstrator and the use of MRA as a prop for local interaction.

### **9.2.2.a Awareness**

Inhabitants were interested to know about the presence and activities of others in the MRA community. To what extent the MRA technology supports different levels of awareness has already been discussed in section 7.3.4.a. Two Vignettes in particular provide more concrete examples of how inhabitants made use of this in specific circumstances.

Vignette 2 illustrates two different aspects. Gavin made himself aware of what Scott was doing very actively, by moving the MRL MRACell to the 127C MRACell (see section 8.1.2.b). He then reported back to Sam that Scott appeared to be busy in his office. The fact that Gavin was moving the MRL MRACell back to the C9 MRACell was then clearly legible to Sam, who interrupted his activity to re-enter a conversation with Gavin. Vignette 4 then adds to this in two ways (section 8.1.2.d). An arranged meeting between Karl and Sarah was coming up. Before it began, Karl explored the MRA environment extensively using the MRL MRACell. At different points on his route he would have been able to see into the C9 and Bath MRACells, which were intended to be used in the meeting. It appeared that Karl very purposefully made himself aware of the overall state of the environment, the presence of Sarah and the availability of the C9 MRACell, before entering into the meeting. The same vignette also shows Sarah strengthening the link between her MRACell and the C9 MRACell in anticipation of the start of the meeting. When Karl entered, she was clearly aware of the other space and it was her who started the conversation. Finally, informal feedback from inhabitants had already confirmed that the map was a useful feature (see section 7.3.4.b). It was used to gain information about the overall state of MRA as well as more specific information about the relationship between it and the other MRACells.

What can be said in summary is that inhabitants made extensive use of MRA's facilities for keeping aware of different aspects. This extended to being aware of activities in remote physical spaces, to the overall state of the MRA topology as well as the activities within virtual space, for example virtual navigation. Although the above has mainly considered inhabitant's pro-active behaviour to re-

configure MRA with the aim of making themselves aware, it is clear that the resulting configuration then allowed them and sometimes others to be more aware passively of the activities within MRA. For example, once one of the MRACells had been moved to be in visual contact with another, both could then be aware of the activities taking place in the other physical space without any further action.

In comparison to many media space approaches as introduced in section 2.3.1.a, MRA had a different emphasis. Instead of making everyone aware of everything and everyone else at all times, MRA allowed its inhabitants to be visually aware of a number of aspects of MRA at all times (see above) but treated audio separately. Overall this provided for awareness but made social interaction more occasioned. When such connections were established, they were then undoubtedly visible to and legible by others, whether that was from within the physical or virtual spatial frameworks. This legibility then directly supported others' decisions in terms of whether to contact a particular person for example. It might also have had a different effect as Dourish et al have indicated in the context of their media space research. The visibility of such connections can be read by others as an affirmation of personal and professional relationships (Dourish, et al, 1996).

#### ***9.2.2.b Social Interaction across MRA***

Although awareness was of course an important factor, MRA was designed to allow inhabitants to establish and maintain verbal social interaction across it. The following will consider certain aspects of this interaction.

People often used MRA simply to greet each other. This sometimes took the form of waving but also of calling across. For the former the video textures of at least two MRACells needed to be in view of each other, although this could be in the distance. For the latter, two MRACells needed to be in audio range already, which was also the case for more prolonged conversations. The material recorded showed that conversations ranged widely in terms of topic. Work related and non-work related matters were part of most conversations. Issues like collaborative paper writing, the organisation of conferences and establishment of new projects were discussed, while the latest departmental gossip, activities over the last weekend and holiday plans also featured. Vignette 5 (see appendix 11.2.3.d) provides a good example.

Often, future activities were discussed and agreed on. The activities were planned for physical space (i.e. a face-to-face meeting), a different communication channel (i.e. Email) or indeed MRA itself for a later time. Vignette 4 (see section 8.1.2.d ) provides an interesting example. When Karl and Sarah discussed the progress of Karl's PhD during a scheduled meeting over MRA, he brought paper copies of some graphs that detailed results from one of his studies. He referred to these during the conversation and Karl and Sarah then agreed the exchange of these via email for further discussion at a meeting that they intended to have over MRA at a later stage. However, this second MRA meeting was replaced by a conversation on the phone (not included in the vignette), during which the graphs that had arrived in the mean time were discussed. The above shows how different activities (e.g. document exchange, future meeting) were achieved across MRA in tight coupling with other communication channels like Email and the telephone.

In addition, what emerged from all vignettes was that there were very different ways of initiating conversations within MRA. These will be considered in turn below.

### **Arranged Meetings**

There were occasions where meetings had been pre-arranged. Vignette 4, already referred to in the previous section, describes such an event. Karl, Sarah and Rico had agreed to have a PhD tutorial in the MRA. Karl and Rico were not permanent inhabitants of an MRACell and had arranged to use the C9 MRACell instead at a specific time just after the weekly seminar at the MRL. As Rico was not available, the meeting proceeded without him.

### **Taking the initiative**

Most conversations resulted from one inhabitant taking the initiative to speak to another, which is exemplified in Vignette 1 (section 8.1.2.a). Often inhabitants left their MRACells in a place that allowed a view of the environment but was not close enough to another MRACell to allow conversations to take place. This resulted in at least one of the inhabitants having to move their MRACell closer to another, if they wanted to talk to somebody. In vignette 1, Sarah moved the 4.9 MRACell close to the C54 MRACell and initiated a conversation. The conversation is not relevant here but not dissimilar from a conversation people might have on a physical corridor. Once the conversation had ended, the MRA was re-

configured again. Both parties pulled backwards, keeping the other party in view. This appeared to be a result of the interface used: the joystick interface allowed backwards movements just as easily as forwards movements. It also allowed inhabitants to see where the other MRACell was being moved to and whether they had actually left their audio range. However, a side effect was that when pulling backwards, inhabitants often did not see that they might affect the privacy of another MRACell that was behind them.

### **Chance encounters**

Chance encounters were also relatively frequent. In contrast to the interaction in other online communities, chance encounters did not tend to occur in virtual space, i.e. by navigating virtually with an MRACell. These could occur if two or more MRACells were moved at the same time, and through this movement people navigating their MRACells encountered each other in virtual space. The recorded material does not suggest that this type of chance encounter took place. In this sense the promise of designing MRACells to be mobile architectural interfaces was not entirely fulfilled. It is likely that the relatively low number of MRACells contributed to the fact that chance encounters during re-configuration were not frequent. In addition, unlike a physical architectural environment, the virtual public space of MRA was not really used for frequent and extensive navigation. It was much more the spatial framework that allowed flexible and legible connections between remote spaces to be established.

Chance encounters in MRA were much more the result of inhabitants or visitors passing physically through an MRACell already connected to another. One such event was recorded in Vignette 2 when Sam got into contact with Gavin passing through the MRL MRACell (section 8.1.2.b). This interaction is noteworthy because a private MRACell (C9) and a public MRACell (MRL) were involved. Relatively few interactions (in comparison to other MRACells) were recorded at the MRL. The public MRACell was mostly a circulation space and people did not tend to spend much time there. Also, it did not belong to anyone in particular, which meant that others connected to it across the MRA could not generally know who they might bump into. However, this vignette demonstrates that chance encounters could take place here, although relatively infrequently, as was evident from other data collected. The above interaction was made possible by the previously established configuration of two MRACells, which had been initi-

ated by Sam before anyone was in view in the MRL foyer. The positioning of the C9 MRACell in such a way allowed Sam to be aware of events in the other space and this was then made use of to initiate the interaction. As the two MRACells were virtually close by, the video was clearly visible and audio was being transmitted. For example, it was clearly audible that somebody opened the main door and then entered the room.

Vignette 7 then shows how these different methods of establishing contact were also intertwined and happened across the MRA topology (see section 8.1.2.g). Attempts to make contact with people inside the MRA topology often led to chance encounters with others not originally sought. This was the case for instances where the original attempt was made from physical space as well as instances where it was made from virtual space.

In summary, chance encounters in MRA are dependent on the pre-existing topology and the fact that people are physically moving through it. This topology might be a result of a planned re-configuration, for example when two MRACells are brought close together for a specific purpose and then left there. The topology might also have emerged over a longer period with many individual decisions leading to a configuration that brings at least two MRACells into proximity. When such a topology exists, chance encounters between people can occur, when they pass through the physical part of the connected MRACells. If such a topology does not pre-exist, planned re-configuration is necessary to establish social interaction. Finally, chance encounters across MRA occur in parallel to those that take place within the physical parts of the MRA topology, and one can lead to another.

### ***9.2.2.c Dealing with Privacy issues***

A further reason for re-configurations and more general interactions with MRA was the need to deal with privacy issues. As outlined previously, each of the MRACells was embedded in two separate public spatial topologies: virtual public space and physical public space. To maintain control over privacy in their MRACells, inhabitants had to manage access from both of these. In physical space this took place through the opening or closing of doors or window blinds, for example. How this could become a resource even for those accessing a space from its virtual end is shown in vignette 6, where Fred and Sarah concluded that

Sam must be around as the door to the C9 MRACell could be seen open (see section 8.1.2.f). There was also electronic access to MRACells via the telephone for example. This could be controlled through the volume of ring tones or the use of answering machines, but this is not the subject of discussion here.

From the outset MRA was designed to allow inhabitants the management of privacy in a very similar fashion to physical space. Privacy was configured in two ways. Firstly the virtual position of an MRACell controlled how much others could see and hear of it, and secondly the state of its privacy settings (geometry set to open, semi-private or private) controlled the visual access to its physical side in a more deliberate way. Both of these were visually available to all others present in virtual space. The recorded material shows that both of these mechanisms were used, but to different extents.

### **Virtual position**

There were two overall motivations for MRA to be re-configured for privacy reasons. Inhabitants changed the MRA topology so as not be disturbed themselves and they changed it to avoid disturbing others. An example of the first motivation has already been explored previously in section 9.1.1.d. Here two inhabitants reacted to a conversation starting in their audio range by pulling away with their MRACells (see Vignette 5 in section 8.1.2.e).

Regarding the second motivation there were a number of occasions observed by the author where inhabitants avoided disturbing others. Inhabitants increased the distance between their cell and that of others when somebody entered for a meeting, for example. While welcoming the visitor(s) into their physical space, they would often grab the joystick and move to a different part of the environment, resulting in others not being able to overhear their meeting. Inhabitants also sometimes moved away just before making a phone call again resulting in nobody present virtually being able to overhear their conversation. One instance was observed during which two office MRACells were located near the public MRACell in the MRL meeting room. When one of the inhabitants realised that they might disturb the gathering going on in the meeting room they suggested that they should re-locate to a different part of the MRA. Both MRACells were moved away together by their inhabitants, where the conversation was picked up again at a 'safe' distance from other activity.

### **Privacy settings**

The buttons on the joystick allowed each of the MRACells to be set to open, semi-closed and closed (see Figure 25). Of the three states, the semi-closed state was used least frequently. None of the MRACells was set to this state for more than 5% of the overall time (see section 8.2). Inhabitants seemed to prefer to indicate only that they were in and available, or that they were unavailable, whether being present in the MRACell or not. It might simply have been too awkward to keep switching settings constantly. Sarah reported that she found using the keyboard (keys a,b,c) easier to use than the joystick, which meant that she could switch directly between open and closed without going through the intermediate step, which was required with the joystick.

For the remaining two settings, two overall strategies of use can be identified. There were those MRACells that were open for at around 50% of the time and more. These were the C9, MRL, C54 and Bartlett MRACells. Although the first two of these were open considerably longer, this was most likely the result of the author controlling the privacy settings on both of these and using them for testing as well as interaction. Regardless of this, these four MRACells were available to others for a considerable amount of time and inhabitants appeared to feel comfortable with this. The inhabitants of the 127C and Bath MRACell seemed to employ a different strategy, where they kept their MRACell closed for the majority of the time to make the physical side of their MRACells private. Sarah in particular seemed to open her MRACell for periods of actual verbal social interaction, while keeping it closed during other times. Vignette 6 provides a good example of this behaviour (see section 8.1.2.f). Sarah opened the Bath MRACell just for the duration of the interaction and closed it again at the end of it.

As has already been mentioned, setting an MRACell to private not only provided privacy to its inhabitants, but also made them unavailable for others to interact with. Sarah and Scott were only available to others for ~23% and ~32% of the time respectively and this clearly affects how often others could have encountered them, which is reflected in the log data about the spatial relationships these two had with others (see Table 17 and Table 18). Finally, as has been mentioned already in section 9.1.1.e, ignoring what had been set by an inhabitant and transgressing the privacy setting was rare and not regarded as acceptable.



### **Privacy concerns**

Concerns about privacy also led to inhabitants and visitors not using MRA in certain instances. This has already been mentioned in section 7.2.6.c. There were two additional areas of concern, one about recording information during the evaluation periods and the second about not wanting to be in camera view at all.

Inhabitants were alerted to the times of recording in advance and their consent was ensured. Visitors were alerted by signs displayed on the entrances to the various spaces and by inhabitants themselves, who were asked to alert visitors to the presence of MRA. However, one inhabitant was concerned about the information that might be recorded. During Vignette 7, Sarah mentioned that she would wait until the recording had stopped, so that she could phone her bank (see section 8.1.2.g). What Sarah could not have been aware of is that conversations on the phone were not picked up by MRA anyway as the microphone tended to be too far away. Following this, Sarah also asked for parts of a previous interaction to be deleted from the recording, or at least not used in the analysis.

There were also a small number of people who avoided being in camera view, if possible. These were typically visitors to the connected spaces and there were a number of instances where one visitor to Sarah's office would not enter the room when MRA was up and running, asking for meetings to be conducted elsewhere (see Vignette 7 in section 8.1.2.g). Equally, one member of staff at the Bartlett, whose office was located on a different floor from the MRA installation, was very concerned about the installation. One instance was recorded (not represented as a vignette) where a person walked through the Bartlett MRACell holding a sheet of A4 paper in front of their face to conceal their identity. Informal feedback from the people concerned pointed to the fact that these anxieties were at least partly due to the fact that MRA displayed a mirror image of the space it was placed in. This meant that people who entered any of the MRACells would see an image of themselves, which some people were uncomfortable with. Overall, strong privacy concerns were confined to a small minority of people who came in contact with MRA, and work with media spaces has reported on similar problems especially for installations in public places (Jancke, et al, 2001).

#### **9.2.2.d Some additional motivations**

There were a number of other unexpected reasons for re-configuring MRA and these concerned the setting up for others, the use of MRA as a prop for local interaction, and as a technology demonstrator to visitors.

##### **The re-configuration of MRA for others**

Vignette 3 shows one instance where MRA is reconfigured by Sam in preparation for a later meeting between Karl and Sarah (see section 8.1.2.c). After a short chat with Sarah, Sam left the C9 MRACell in visual range of the Bath MRACell but outside audio range as Sarah had requested. This pre-configuration in combination with strengthening of the MRLink by Sarah then allowed her to be aware of activities in C9 (see section 8.1.2.d).

##### **The use of MRA as a technology demonstration to visitors**

MRA also became very popular as a technology demonstrator for visitors to the various labs it connected. There it was used to introduce the type of research that a group was doing. Informal feedback suggested that a number of people also simply liked its reliability, not necessarily as a tool to be used but as a demonstrator. They could rely on it being there and up and running even for unannounced visits.

##### **The use of MRA as a prop for local group interaction**

Finally, a more unexpected reason for MRA re-configurations is related to the above but serves a different purpose. Vignette 8 shows an instance where MRA is used solely as a prop for local interaction in the Bartlett MRACell (see section 8.1.2.h). It was Thomas's birthday, which was being celebrated at the Bartlett with some cake and people gathering around the meeting table. During this interaction, inhabitants moved this MRACell closer to the C9 and MRL MRACell respectively, without making any serious attempts to involve people located there in the local interaction. Showing the cake to the camera became a local joke around which much of the interaction then evolved. The interaction itself had no effects on any of the inhabitants that might have been reached across the MRA but only on those present in a single MRACell. However, the effect of the re-configuration was on the entire MRA topology.

### 9.2.3 The social network of MRA

As has already been suggested in section 7.4.1, locations for MRACells were chosen opportunistically. MRACells were installed where an opportunity arose, depending on whether people responded positively to a request by the author or requested an MRACell themselves. Therefore there was no conscious effort at the outset to model the MRA community on any particular social network.

However, as the process was centred on and carried out by the author himself, the resulting community was in fact also a replication of the author's social and professional network: all the inhabitants knew the author. As it happened, most of them also knew each other as they were participants in the EQUATOR project (Rodden, 2000-2006). The exception was the Bartlett MRACell, where most people were only known to the author and Scott at the 127C MRACell. In fact Scott and Peter had initially suggested the installation of MRACells at the Bartlett and in 127C as a means to strengthen their ties.

The material introduced in the previous sections then clearly shows that MRA was able to maintain and reinforce that network. Existing social relationships have been maintained over MRA as for example between the author and Kate as well as the author, Kate and Sarah. In addition, existing social relationships were strengthened as for example between the author and Scott, the author and Peter as well as the author and Fran. Maintaining and strengthening social relationships appeared to be the main functions of MRA in its present form. However, in some instances new social connections were also established. Peter and Sarah reported that MRA allowed them to establish the initial contact and social relationship that was necessary in order to discuss a common project proposal. This also included two other colleagues at the two respective sites.

At the same time, some existing social networks seemed to be unaffected by MRA, in that no significant contact was recorded for two pairs of inhabitants who were known to each other and who had at least a professional relationship: Peter and Scott, and Sarah and Scott. Evidence for this comes from the lack of social interaction between them that was recorded on tape, but also from the log data statistics (see section 8.2.3, Table 17 and Table 18 (the relatively long connection of the 127C and Bartlett listed in the table originates from one single instance)).

This particular combination of inhabitants had a very small chance of meeting each other because they were unavailable to the others for the majority of the time: Sarah and Scott because they kept the MRACells set to private a lot (see section 8.2.2) and Peter because he was not actually located in his MRACell. On request, Peter reported that whenever he attempted to speak to Scott, Scott was not available, having his virtual door closed. Scott stated that he used the MRA relatively infrequently, because he was so often out or in meetings.

All this taken together then resulted in a new social network: that of the MRA itself. This was defined by membership of the MRA in some form and incorporated all core inhabitants and some permanent inhabitants: Kate, Sarah, Scott, Peter, Gemma, Xantia, Beatrice, Fran, Ian and the author himself. Some of those were part of the core network only temporarily, as their work space moved into and out of the MRA topology. This was the case for example for Gemma and Xantia in the C9 MRACell. Besides this there was a much larger secondary social network that MRA provided inhabitants at least some access to. This can be seen from the vignettes. In total, 38 different individuals appear in the transcriptions of the recorded material.

However, social networks are never static. They change over time and this also was the case for the MRA social network. As already mentioned, some members simply moved out of the MRA topology and new members came in. It also appeared that new social networks, established through new work situations, replaced existing social networks. A case in point was Sarah who moved from Nottingham to Bath University. MRA allowed her to maintain her existing social network in Nottingham. However, as time progressed, new commitments at Bath took over and time spent with people at Nottingham across MRA became less. However, this did not mean that the relationship ceased to exist altogether. It was simply the case that a change in members' social networks had a direct impact on the social network of the MRA, while Sarah's new and old social networks also overlapped.

In summary, MRA supported the existing social network over distance very well, helped to strengthen it and managed to extend it, although only in a very limited way. Simply providing connections between people, in effect increasing the population density by minimising the perceived distance between them, did not on its own lead to new social contacts a point made previously in the media

space literature (Fish, et al, 1990) and about the telephone network (Steadman, 1999). In this context, the lack of social interaction between inhabitants of the Bartlett MRACell (apart from Peter and Fran) can be explained by them being outside the original social network (they were not part of the EQUATOR project) and also having a different background and possibly different set of interests (they were Architects rather than Computer Scientist). For people from the Bartlett to be more included, organised events or more formal introductions might have helped. Overall, MRA was used for interaction very much in an occasioned, motivated way. Once there was a social connection with someone or there was a requirement to work together, MRA greatly facilitated the resulting interaction.

### ***9.3 Perception in Mixed Reality Architecture***

Movement through architectural configurations is crucial for how we perceive them. The introduction of MRA topologies then raises the question of how our cognition of architectural space is affected by this. At the same time it is of interest to explore what might be derived more generally for the understanding of cognition in Mixed Reality spaces, especially with the latter becoming more widespread. The present outline of how this might take place is grounded in the results of the MRA research as presented previously. However, to address this question it is first necessary to briefly outline the three main approaches to environmental cognition.

#### **Environmental cognition**

Relatively recently, the ‘embodied-embedded’ approach to cognitive science began challenging more traditional views (Wheeler, 2005). This new approach has at its core the idea that for an understanding of cognition, brain, body and environment cannot be analysed and described separately. Wheeler’s work focuses on the philosophical foundations of ‘embodied-embedded’ cognitive science, proposing a re-application of Heideggerian philosophy to cognition. This in itself would go beyond the discussion presented in this thesis but Wheeler provides a useful overview of the overall approach. He criticises both classical and connectionist perspectives on Artificial Intelligence (AI), a field that has struggled to find a model for cognition that could be simulated. In addition, Wheeler argues, both of the traditional takes on cognitive science have not been able to explain convincingly how animals and humans experience the world.

Dreyfus' influential account of AI had already criticised classical approaches for attempting to build intelligent machines that depended on representations of their environment (Dreyfus, 1992). Dreyfus points out that these representational states were also seen as critical for our own perception. After very rapid initial successes in the 1960s, the classical approach to AI failed to deliver when it came to coping with changing environments, while it was very successful at complex reasoning on complex problems (Dreyfus, 1992). As an alternative to the above Dreyfus argues for addressing cognition from a Heideggerian view point. From this perspective knowledge about the world becomes much more *knowing how* to act rather than gathering, storing and acting upon abstract facts. Therefore, the world becomes relevant to us in terms of how we might be able to act upon it, a perspective that has been introduced as the concept of affordances to industrial design by Norman, which in turn is frequently referred to in Human Computer Interaction (Gaver, 1991, Norman, 1988). In response to the difficulties of the classical approach, the connectionist approach to AI originating in the 1980s focussed on the use of neural networks to simulate the learning mechanisms of organisms. Connectionist AI had a series of early successes in particular because it was far more flexible than the classical approach when dealing with environmental change. However, this approach still faced insurmountable problems in not being able to recognise and react to different contexts from those where learning had taken place, and in its inability to sufficiently generalise from one situation to another (Dreyfus, 1992).

Wheeler argues that both the above approaches to cognitive science are limited to what he terms 'offline intelligence' (Wheeler, 2005). Offline intelligence is concerned with reflection: e.g. wondering about what the weather might be like tomorrow or advance route planning. Indeed, the internal representations that 'offline intelligence' can provide must be seen as absolutely essential to these activities (Clark, 2001). 'Online intelligence' is characterised by Wheeler as 'suite of fluid and flexible real-time adaptive responses to incoming sensory stimuli' (Wheeler, 2005). In contrast to classical cognitive science this is seen as occurring in an extended system of brain, body and environment. The author argues that cognition cannot be separated from our bodies, since bodily features clearly affect our perception of the world. For example, the position of our eyes gives us a very specific type of vision. Equally, cognition cannot be separated from the environ-

ment in 'online intelligence'. The 'embodied-embedded' approach proposes that our perception of the world depends on frequent and continuous sampling of our surroundings, instead of the continuous reference to an abstract representation of the environment as the traditional approach to cognitive science suggested.

These issues have come to the fore most prominently in AI-oriented robotics research. Here the emphasis is on developing robots that cope smoothly with real environmental settings (Wheeler, 2005). Wheeler points out that through this research the notion of representation is transformed. Here objects are represented in a contextualised way. Through frequent sampling, these systems build up temporary snap maps of the environment based on an ego-centric coordinate system, which includes information about obstacles and targets and can result in appropriate spatial navigation. Furthermore, researchers take advantage of the physical properties of the robot (e.g. its body) to support cognition. The world is therefore encoded as possibilities for action dependent on the nature of the robot's body, and Wheeler argues that it is plausible that his action-oriented approach can also be found in human beings. Heidegger's philosophy, which Wheeler interprets and applies to cognition, has described 'being' in similar terms (Wheeler, 2005). The long term analysis of MRA has prompted the following application of the 'embodied-embedded' approach to cognition in Mixed Reality spaces.

### **A dynamic extension to the environment**

The discussion of spatial adjacencies, the resulting changes in spatial integration of physical spaces and of the virtual spatial topology has clearly demonstrated the dynamic nature of MRA. Based on these points, it has been argued that the environment that inhabitants physically moved through was directly affected and this in turn influenced the movement of inhabitants. There are two aspects to this. Firstly, the environment that is perceived and navigated is extended into virtual space and this extension adds a dynamic aspect to the overall inhabitable environment. Secondly, the available environment is extended into remote physical space. Neither of these types of extension to the architectural palette has been considered previously in the discussion of architectural configurations (Steadman, 1983) (Hillier, 1996) (Penn, et al, 1999). At the same time, one must not overstate this point, since access to MRA is evidently limited as has been

pointed out previously. The experience with study 2 has then shown that this aspect of MRA, the dynamic extension of the environment into virtual space and into remote physical space, constitutes what permanent inhabitants and visitors mostly perceived of MRA, as has been argued in section 9.2.1.

### **An extension to the body**

In addition to perceiving MRA as a dynamic extension of their environment, core inhabitants did perceive MRA in another manner. They directed most of the virtual movement of the individual MRACells. It was mostly them who interacted with the joystick interface and actually navigated through the virtual extension of the environment, although of course in many cases permanent inhabitants and visitors were passive observers of this movement. The sense of movement through virtual space was provided by the joystick interface, where physical movement was quite literally translated into virtual movement. This was coupled with the changing imagery on the projected Mixed Reality Boundary. This is not unlike other virtual reality interfaces, and the role of embodiments has been discussed in detail in the literature (Benford, et al, 1995, Bowers, et al, 1996, Hindmarsh, et al, 2000).

One might argue that in this way, although originally designed to represent a spatial entity, the MRCells became an extension to the embodiment of the person navigating with it. The virtual part of the MRACell acted as personal representation or avatar in virtual space, which provided the senses of vision and hearing in that space. The vignettes have then shown how the position and orientation of these representations have gained social meaning. The MRA technology as a whole extended the scope of inhabitants' speech and the scope of their representation to be seen (in the form of their video image). Equally, others in the MRA have referred to MRACells by the name of the person of its permanent inhabitant (if no permanent inhabitant existed for an MRACell, it was referred to by the institution it belonged to) and this points to the possibility that MRACells had become extensions to inhabitants' embodiments in the eye of other inhabitants, too. Finally, inhabitants' bodies have also been extended into remote physical space although in a more limited way. Vision and hearing were supported, while movement was not.

In summary, it might be said that MRACells mainly became bodily extensions for core inhabitants. This notion is particularly strong during navigation and similar



to other VR interfaces. For permanent inhabitants and visitors (in addition to core inhabitants when they were not navigating), MRA appeared much more as an extension to the environment. In this way, MRA might have appeared to this group of inhabitants in a similar way to typical media spaces.

### **Movement**

Overall, as has been exemplified in the vignettes, inhabitants had two ways of moving through this environment. They could move physically. This movement was mostly local to their work place. Once inhabitants encountered one of the MRACells, this physical movement could go over into virtual movement. Walking up to the MRB in the MRA topology and interacting with the joystick to navigate, ended physical walking from which point, virtual navigation could commence. The framework in chapter 3 has described such a situation in terms of the use of the 'ideal' interface. Here physically walking through a virtual boundary that contains an MRLink, would switch the user's perception from physical space to virtual space. In MRA, this translation of physical to virtual movement is effectively reserved for core inhabitants as has been pointed out before. The resulting movement allows navigation within virtual space. It also allows the reduction in the perceived distance, across virtual space, to remote physical spaces, while it does not however allow movement within those remote physical spaces. Both types of movement, physical and virtual are then guided and shaped by the changing topology of MRA. For the perception and understanding of the overall topology of MRA, this movement is essential, just like the movement through physical spatial topologies. In this way, MRA offers something over and above the original MRB technology as well as other virtual reality systems: it combines an extension of the environment and the embodiment into virtual and remote physical spaces, at least for some of its inhabitants.

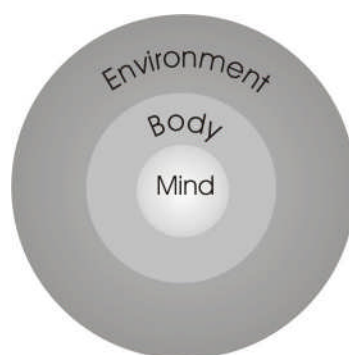
### **Coping Smoothly**

In terms of 'being' in the extended Mixed Reality space of MRA it is interesting to note that people seemed to have no difficulty to cope smoothly with stimuli from both sets of the environment at the same time. Participants were observed to be using the telephone while pulling away from another MRACell (see section 7.3.4.b for examples). This type of interaction might then also be followed by a conversation with another person present in the same physical room. This ability is of course critical for our use of general Mixed Reality space. At the same time,

after inhabiting and analysing MRA for such an extended period of time, it seems somewhat unremarkable. This is especially so when one considers other technologies like mobile phones that are routinely used in parallel with other ongoing activities. But maybe this ability is simply an indication of the fact that body and environment did indeed become extended into virtual space. Or it might be that humans simply have this ability and can exercise it across a range of different media as long as those media do not hinder their activity. In summary, what is clear is that without the ability to cope smoothly with stimuli from different parts of Mixed Reality space and without a design that supports this ability, this new type of environment would quite possibly be unusable for everyday social interaction.

### **Environmental cognition in Mixed Reality spaces**

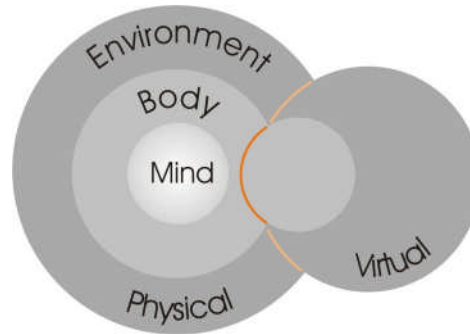
It is now worth generalising what has been found in regards to cognition in MRA to general Mixed Reality space. If, according to the ‘embodied-embedded’ approach, brain, body and environment cannot be separated in the analysis of environmental cognition, the latter must clearly be affected by the extension of body and environment into virtual and remote physical spaces. The following arguments concern cognition within or across Mixed Reality since cognition of physical space away from a Mixed Reality installation is not affected (it might well be affected by other technologies such as the mobile phone). For the purposes of this discussion, cognition in physical space according to the ‘embodied-embedded’ perspective might be visualised as follows. The mind is embodied in the physical body which is embedded in the physical environment as shown in Figure 79.



**Figure 79 The mind embodied and embedded**

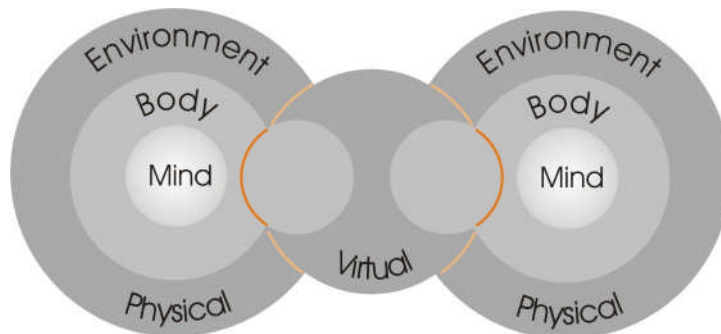
For a single user environment, the environment that a person is embedded in becomes extended into virtual space. This changes the nature of their

embeddedness in the environment. As part of the interface to Mixed Reality people are given a certain type of access to that virtual space and therefore their body or embodiment in the world is also changed or extended. Figure 80 visualises both extensions. The orange lines indicate the MRLink that becomes necessary and whose quality and location in relationship to body and environment determines the type of access to Mixed Reality space.



**Figure 80 The extension to embodiment and embeddedness**

The situation changes again once a remote person enters the same Mixed Reality space. Both people experience extensions of their bodies into the shared virtual space. Both also experience an extension of their physical environment into remote physical space across the shared virtual space. The other person becomes part of the shared environment as shown in Figure 81.



**Figure 81 Two people in extended MR environment**

What is critical in this discussion is that these two types of extension are not equally accessible in Mixed Reality space. In chapter 3 it has already been argued that access to Mixed Reality can be individualised, meaning that different people might get different types of access to the same underlying virtual space, while they might also access different virtual spaces although being in the same physical space. The experience with MRA has then shown that although the MRB interface technology was accessible to everyone close by since it was a public in-

terface, the patterns of use have meant that it was experienced differently by different groups of people. Therefore, the cognition of MRA was clearly defined by the quality of its interface in addition to the differences in use that have evolved over time.

### **The shape of cognitive Mixed Reality space**

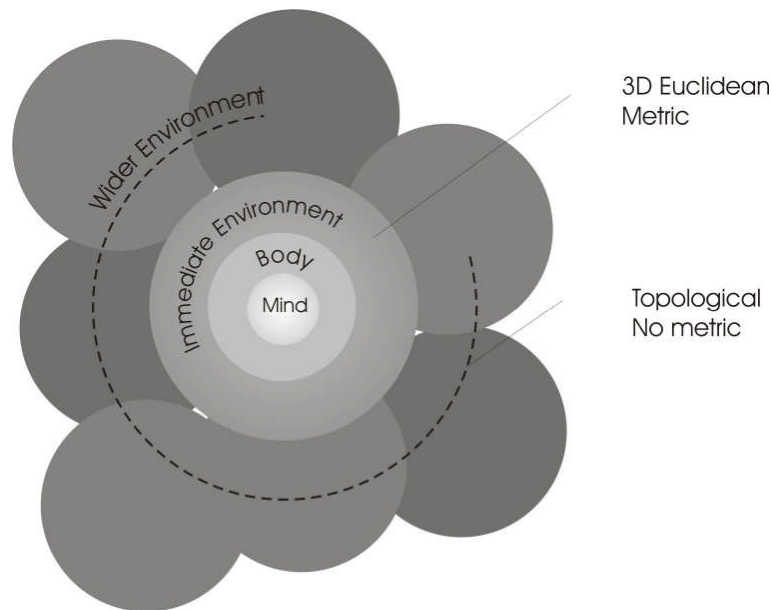
The shape of the cognitive space in Mixed Reality is determined by the properties of its two components: physical space and virtual space. For physical reality it can be argued that cognitive space is three-dimensional with a Euclidean metric. Within physics there are certainly a number of other explanatory approaches concerning the structure of physical space but Einstein proposed that these are mainly a function of various conceptual schemes necessary for the explanation of particular phenomena (Jammer, 1993). So although for example Einstein's General Theory of Relativity provided a much deeper understanding of physical reality by subordinating the notion of space to the notion of the field, Jammer argues that Newtonian space will always be the framework for our daily experience (Jammer, 1993).

Penn points out that while this can certainly be the case for the immediate physical space, which directly surrounds a person, the shape of cognitive space relevant for spatial configurations is topological in nature. He argues that it is not metric as it can for example be shown that 'the distance of a route in one direction appears (cognitively) different to the distance in the opposite direction' (Penn, 2003). Lynch presented similar arguments about the representations of urban space that people are capable of producing (see section 4.2.4 for more details).

*'It was as if the maps were drawn on an infinitely flexible rubber sheet; directions were twisted, distances stretched or compressed, large forms so changed from their accurate scale projection as to be at first unrecognizable. But the sequence was usually correct, the map was rarely torn and sewn back together in another order.'* (Lynch, 1960)

The following graphic illustrates such a space with the immediate environment adhering to a three-dimensional Euclidean metric, while our cognition of the wider environment, represented as darker circles in a loose structure, becomes relevant to us through the topological relationships between spaces. When mov-

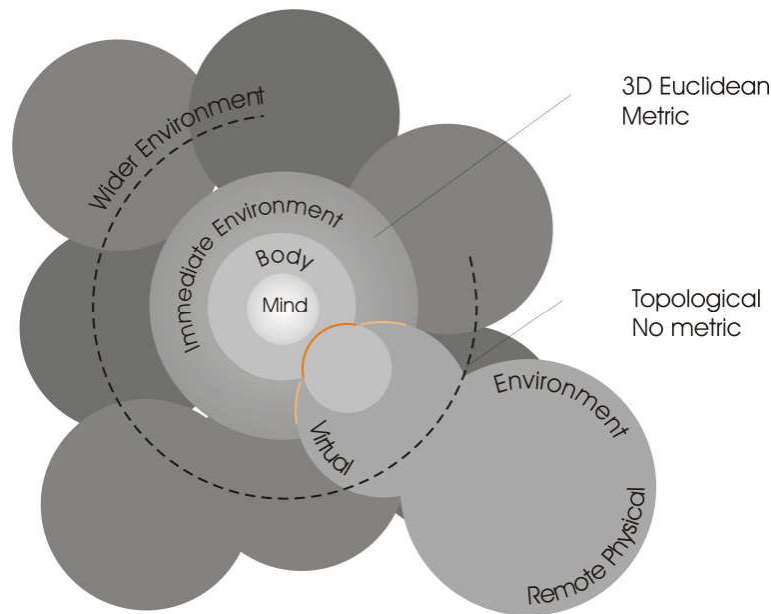
ing through such a configuration, different parts become immediate to us and 'their' three-dimensional Euclidean metric nature dominates our perception.



**Figure 82 Cognition of immediate and wider physical spatial configuration**

When considering the addition of virtual spaces to the configuration one must think about the two possibilities that were introduced in sections 3.3.4.a and 3.3.4.b. If the spatial relationship between physical and virtual spaces is systematically mapped, then typically there is a one to one relationship between the coordinate systems of physical and virtual spaces. This makes it necessary for virtual space to adopt the same metric as physical space and our cognition of this type of Mixed Reality space is likely to be very similar to that of physical space, with the cognitive difference between immediate and wider environment replicated.

The Mixed Reality space of MRA has not specified a spatial relationship between its physical and virtual spaces and this is the second principal topology. This might be visualised as shown in Figure 83. The immediate physical space is extended into virtual space and across that into remote physical space. This requires the establishment of at least one MRLink but multiple MRLinks can exist at the same time. The possible properties of such links have already been outlined in section 0.



**Figure 83 Cognition of Mixed Reality spatial configuration**

Cognition of this type of Mixed Reality space then depends in large part on these properties of MRLinks. It also depends on the social practices that might have evolved over time around such MRLinks as reported in section 9.2.1. In the simplest case and unlike MRA itself, the MRLink is static, its target is fixed and it is public in that it is accessible to everyone spatially close by. In this case the cognition of Mixed Reality space is arguably similar to that in physical space. Local space appears as Euclidean three-dimensional with a defined metric. The wider spatial configuration, which now includes physical and virtual spaces, becomes cognitively relevant through its topological spatial relationships. Metrics are not relevant in this case, as no spatial relationship between physical and virtual spaces has been specified in this second approach.

Of course, MRA itself has investigated MRLinks that are virtually mobile. In this case, which part of a shared virtual space is linked to and which remote physical space is accessible, changes over time. Once MRLinks become physically mobile in addition to being virtually mobile, there are no fixed points in the Mixed Reality topology anymore. When perceiving such an environment, references to previously experienced configurations are most likely meaningless, because the overall configuration has probably changed. Cognition of such spatial systems must therefore rely totally on inferences that are made from within local space ad hoc and every time the spatial configuration changes.

Finally, one can only speculate what these arguments might mean for the use of the 'ideal' interface as introduced by Deutsch and discussed in chapter 3 (Deutsch, 1998). If our experience of physical reality is dependent on our bodies, one needs to consider what happens, if parts of our body are bypassed. Our body is part of our cognitive system from birth. For example, the position and orientation of our eyes give us a particular sense of vision which affects how we perceive the world. Deutsch suggests bypassing our sense organs as part of an interface direct to our nervous system (Deutsch, 1998). He argues that such a split of brain and nervous system on one side from physical body and from environment on the other side is theoretically imaginable and will eventually be practically possible. It seems that as long as the signals fed directly back to our nervous system accurately simulate the properties of our physical bodies and our physical environment, we as human beings will be able to perceive the artificial environment as if it was real. As soon as the simulation of the properties of our bodies and indeed the properties of environment deviate from physical reality we would have to adjust completely. Indeed it has been shown previously in an entirely physical context that humans have the quite amazing capability to adjust to similar transformations, as studies that experimented with the artificial inversion of participant's fields of vision have shown (Stratton, 1896) (Snyder and Pronko, 1952). However, whether and how this might translate to the direct rendering of virtual space is entirely unclear as such interfaces currently do not exist.

This final section has concentrated on the cognition of Mixed Reality spaces and has attempted to provide answers based on the application of the 'embodied-embedded' approach to Mixed Reality. However, what seems clear from the above is that environmental cognition as a field will need to consider digital extensions to our bodies and environments as a given feature of our present world and these extensions need to be permanently included in the overall explanatory scheme of cognitive science of reality. As Mixed Reality environments become more commonplace on the back of the rapid development of digital technology, it seems clear that there will be a point where we as humans will never perceive a digitally unaugmented reality through a digitally unaugmented body.

# 10

## Conclusion

The focus of this research has been Mixed Reality Architecture, which combines physical and virtual spaces in its topology. It was of particular interest to investigate how architecture could be made more topologically flexible and how to make social interaction across communication technologies more legible and accountable through the application of architectural features. This chapter first reflects on the research that was conducted for this thesis before providing an outlook on the possible future uses of MRA.

### *10.1 Reflection*

There were a number of key initial drivers for this work as outlined previously. It has been argued that architecture can be described as structuring co-presence within physical space while at the same time being structured itself by the society



living within it. In turn, social interaction taking place within physical space is accountable to and legible by others. Also, its framework, the architectural topology around us, is very stable. Changes to it certainly do occur but they are relatively slow and costly.

At the same time, the ubiquity of telecommunication technology means that social interaction has become extremely flexible and is not bound by physical spatial limitations. Remote social interaction is of course commonplace through this technology. However, this remains hidden from view and the structuring effect this technology might exert on society is invisible. This use of communication technologies is also one of the reasons why modern organisations frequently span multiple physical sites and are organisationally very flexible. Organisational changes are typically dealt with by re-organising people within space, but change often goes much further than that, when buildings are adapted to meet new requirements.

Taken together this provides the rationale for the research conducted for this thesis. The aim has been to investigate how architectural topologies might be made more flexible with the tools that communication technologies provide, and how communication technologies in turn might benefit from a very specific architectural approach to remote social interaction. In response the concept of Mixed Reality Architecture (MRA) has been proposed, designed, constructed and evaluated. The following provides a summary of the main stages in this process.

### **10.1.1 Framework**

As a first step, a framework has been developed to explore the theoretical aspects of Mixed Reality as resource for architecture developed in this area but also for more general Mixed Reality systems (see chapter 3). This framework charts the field of possible architectures that can be created when physical and virtual spaces are combined. A brief overview follows.

#### ***10.1.1.a The constituent parts of MRA***

The first section considered physical and virtual spaces in terms of their flexibility, what types of access we are granted to them, co-presence between people and the limits of experiences within them. It has been argued that our perception can be equivalent for both types of spaces when a fully transparent interface is used,

which in turn means that any limits in experience are then caused by our own bodies rather than a specific interface technology. Virtual space supports co-presence of people who are present within it, just as physical space does. However, access to virtual space is clearly limited even with a transparent interface as our bodies will always remain in physical space. Crucially in this context, virtual spaces have been identified as highly flexible allowing rapid changes in their shape and extent, although there will also always be lower limits on this.

The second section then considered the links between those two categories of space and focussed on how flexible Mixed Reality Links are, what type of access we are granted across them, what this means for co-presence and what types of target for an MRLink are conceivable. It has been argued that how links are conveyed to us is a matter of design and that they could appear in a very similar form to links between physical spaces. They are very flexible in terms of their targets and their position; and they can also be fragmented to link the same two spaces in multiple places. Access across any link is limited as our bodies will always remain in physical space. Instead we are typically required to take on an additional representation when crossing into virtual space. Access can also be tailored to different individuals and can be used to exert control over people's movements as is the case with physical spatial links. As virtual spaces and Mixed Reality Links can potentially be individualised, it is a matter of design to support co-presence between physical and virtual spaces.

The final section of the framework then set out the concept of Mixed Reality Architecture as a configuration of physical and virtual spaces joined together by Mixed Reality Links. MRA was discussed in terms of how flexible it is, what access can be gained to its parts, what its topology is like and how MRA affects co-presence. It has been argued that MRA is experienced through its constituent parts: spaces and links. However, experiencing and comprehending it in its entirety requires exploration. MRA can be described as topologically very flexible, although from the perspective of each inhabitant it is anchored to the physical space to which they have full bodily access. Access to different parts of the MRA topology is entirely dependent on the access granted to its parts. The MRA topology itself is determined by the physical topology, one or more virtual topologies and the relationship between those. This relationship can be systematically mapped or can be left unspecified.

Finally, the relationship between the MRA topology and the society inhabiting it has been identified as a key research area. It was of major interest to investigate fully how MRA can influence co-presence between inhabitants and how their actions can influence the topology.

#### *10.1.1.b Mixed Reality Architectural Cells*

This framework has then led to an initial pilot study, the description of which can be found in chapter 5 and which is also summarised briefly in the following section. Reflecting on the findings of this study and responding to the requirements of the new application area chosen for the main study, the key concept of the Mixed Reality Architectural Cell (MRACell) was introduced. MRACells are modelled on physical architectural cells and their support for the co-presence of people within them, as well as on the control they provide over access given to different categories of people. MRACells consist of one physical and one virtual space and these are permanently attached to each other. The possible topological relationship of these two parts was outlined and two concrete designs were suggested for their actual implementation: an early design and the final design used in the main study for this research.

MRACells are the basic building blocks of MRA. They are embedded simultaneously in one physical topology as well as one virtual topology and provide their inhabitants with full control over access from both of these, in a very similar way to physical architectural cells. In addition, they are virtually dynamic, allowing inhabitants of MRA to establish different architectural topologies according to their requirements. This occurs by inhabitants of MRA being able to position their MRACells anywhere in virtual space, in the process changing the relationship between their MRACell and all others. Therefore, MRACells allow the construction of an architecture that follows possibly the ‘shortest model’ that is architecturally conceivable. In this sense, MRACells can be described as novel architectural interfaces: spatial relationships between multiple MRACells are not pre-specified in design, but are entirely dependent on the interaction by inhabitants. In the process, they enable and control social interaction between people who are not physically co-located. In contrast to the most commonly used telecommunication technologies, this process is available and legible to others embedded in the same spatial framework. In turn, this has clear effects on the

overall MRA topology. Through these reconfigurations inhabitants can create spatial connections between different remote physical locations on the fly, so creating a dynamic Mixed Reality Architecture.

### 10.1.2 Prototyping MRA

The considerations of the original framework, as presented in chapter 3 and as outlined again in the section above, led to an iterative design and prototyping process as the main method of enquiry, using early and continuous evaluation. Further developing the concept of MRA required the design, construction and long-term evaluation of MRA in an everyday setting. Although it was possible to base certain design decisions on precedents partly derived from existing experience with related technologies and set-ups, it was also clear that many issues would only come to light when actually inhabiting MRA.

This process had to reflect currently available technologies and the work practices at the given settings. It was motivated by the novelty of the concept, the lack of practice around that concept, the distributedness of the prototype and the situatedness of the prototype. These issues were discussed in detail in chapter 4 in addition to the main methods for evaluating MRA: situated observational studies, interviews, sketch maps and the replaying of virtual environments. Two major prototypes of MRA were then developed within an everyday office environment. In addition, the second prototype was also iteratively refined through a series of smaller prototyping steps.

#### *10.1.2.a Study 1: Presenting in Mixed Reality*

For this study, a prototype MRA was set up that provided an environment for distributed presentations given by local and remote speakers to local and remote audiences. It linked four physical spaces across one virtual space. The study took the form of a staged event and focussed on a number of key issues with the aim of starting to evaluate the concept of MRA, especially in terms of its dynamic properties and its influence on co-presence between people not physically co-located. It was also concerned with gaining a better understanding of giving presentations to distributed audiences, where speakers and audiences communicate over a computer network instead of physically travelling to meet face-to-face. In contrast to previous work that has addressed this application area, here,

an approach was taken that combines a physical spatial framework for local participants and a virtual spatial framework for remote participants into a shared MRA embedding local and remote speakers as well as audiences.

Presenting in Mixed Reality was broadly successful in demonstrating that Mixed Reality Architecture could be used for distributed presentations and in establishing the relevant issues needed for further development in the prototyping cycle of MRA. The presentations by local and remote speakers to a mixed local and remote audience were well supported, although they were not without difficulties. The presentations and the question and answer sessions that followed showed that talks to medium sized audiences at least can be well supported within MRA in principle.

More importantly, the results showed that establishing an integrated Mixed Reality space was clearly possible with MRA, although this depended on the interface. The MRB technology had clear advantages over the use of desktop screens, in that it required no training, was large enough to provide good visual access to a group of people and crucially in that it allowed a visual link back from virtual to physical space. The MRB technology was therefore chosen for the further development stages of MRA. The need to deal with multiple MRBs in a single virtual spatial framework as well as the requirements of a new application area then led to the extension of the original framework for MRA (as mentioned in section 10.1.1.b and detailed in chapter 6). In addition to the above, it was also clear that the topological dynamics introduced for the pilot study were too limited. They were limited to a specific event and to the control by the overall owner of the MRA. The investigation of more general topological dynamics controlled by inhabitants of an MRA was identified for further research. For this reason an activity was chosen that followed a 'short model' avoiding limits on social and spatial relationship in contrast to the first study, where the presentation task clearly followed a 'long model'. Here, the nature of the activity quite clearly restricted the possible social and spatial relationships.

#### ***10.1.2.b Study 2: Mixed Reality Architecture***

For this second study, an initial interview survey was conducted that allowed a base line description of the social networks existing within the various settings. These social networks were all related to academic research and their most strik-

ing - while possibly obvious - feature was that they tended to span multiple physical sites. First of all, in their office spaces, people were not co-located necessarily with their immediate work colleagues and secondly, many direct work colleagues were based off-site in relation to the respondent (see section 7.1). This provided an ideal test bed for MRA.

The first phase of the prototyping cycle was an initial pilot study with three MRACells, conducted during October 2003. The second phase was a follow up study with four MRACells conducted between January and June 2004. The two phases of the development (see chapter 7 for a full description) took place within the day-to-day activities of the MRL, a working and very active research environment. The overall aim of the evaluation of the two prototypes was to better understand issues in the design, construction and use of MRA. This required an evaluation of the suitability of the implementation and the concepts that led to its design but also the uncovering of additional unforeseen issues. These earlier findings were then fed back into the development cycle, resulting in a robust and useable implementation that could be evaluated longer term, with MRACells located locally but also at sites that were physically remote from the MRL.

This longer term evaluation of the final prototype then took place between July and October 2004 (see chapter 8). For this final phase of the study of MRA, two evaluation methods were used. The main method was an observational study. This was supported by recording and replaying virtual environments. The combination of these two allowed the production of vignettes (see section 8.1.2 and appendix 11.2.3), describing a selected group of interactions in very fine detail with the aim of abstracting larger issues from these. In addition, the analysis in general was also supplemented by more informal feedback from inhabitants and information drawn from the diaries that some inhabitants kept of key events. Additionally, the data logs recorded within the virtual environment allowed the quantitative analysis of patterns of use over longer periods than the observational study allowed (see section 8.2). Before summarising the discussion of the findings of the second study, it is worth reflecting briefly on the relationship between the original framework and the two studies.

### *10.1.2.c Relationship to framework*

Building MRA, in form of the two prototypes discussed above, required a concrete implementation of parts of the theoretical framework of MRA. In particular, a specific interface technology had to be chosen, because a 'direct' interface as imagined by Deutsch does not currently exist (Deutsch, 1998). As already mentioned these interfaces were one HMD, a number of desktop computers and one MRB for the first study and multiple MRBs for the second study. Although these technologies are quite different, they influenced the experience of MRA in a similar way. The following focuses first on the commonalities between the two studies in their relation to the framework before proceeding to the main differences.

As the interfaces chosen were external to our nervous system, their main effect was to limit our access to virtual spaces across MRLinks. They were much more a window into virtual space, providing a view into and audio from it, while projecting audio and a representation of the user into it. This resulted in access being very different from the various parts of an MRA, because physical parts were fully accessible, while virtual parts were clearly not. However, as these technologies were embedded in two democratically available spatial frameworks, that of physical space and that of virtual space, their use was available to everyone in principle. Even the HMD technology, although individual when used, can be passed on to another person. This also clearly limited the experience of virtual space and MRLinks. The MRLink was effectively the interface technology, and designing how it appeared very much depended on the existing form of that technology. Also, the limits to our experience of virtual space now resulted first from the properties of the interface technology used and then from the limitations of our own perception. In terms of designing the two MRAs, there were further similarities. Targets of MRLinks were other spaces in both studies. Which spaces these linked to was pre-defined and did not change over the course of the experiment, while this was clearly more flexible for the main study. Additionally, there were also no temporal transformations and access was synchronous.

There were also some key differences between the studies in their relation to the framework. Although interface technologies clearly limit our access to and experience of virtual parts of an MRA, a sense of co-presence was well supported

within the MRA topology, as the two studies have clearly shown. For study 1, this was achieved with two types of virtual representation: avatars and the live video image provided. For study 2 only the live image was used. Much of the evaluation work has focussed how exactly co-presence was supported in practice.

In terms of topological flexibility, the two studies were very different. For study 1, it was effectively limited to the change of elements within the virtual space that gave an impression of topological flexibility. This occurred only once and was controlled by the researchers conducting the study. The physical presentation space was permanently linked with one MRB to the virtual presentation space. These units were physically static and their topological relationship systematically mapped. The desktop interfaces and the one HMD then allowed the exploration of the architecture, while participants using the MRB itself were not afforded any navigation.

For study 2, topological flexibility was fundamental, with inhabitants having full control over the changes. The concept of MRACells was introduced that also permanently linked one physical to one virtual space with one MRB each. However these were virtually dynamic, which resulted in topological flexibility being fluid, with the topology frequently being adapted to new requirements. The topological relationship between the physical space of the MRACells and public virtual space was left unspecified. Finally, as study 2 has shown (see the following section), social interaction within MRA and its topology clearly influence each other. Inhabitants re-configured the MRA topology according to their requirements, which in turn influenced social interaction within MRA.

### **10.1.3 Architectural implications**

The relationship between the dynamic architectural topology and life within MRA is key to the discussion of this research. As has been pointed out, the framework raised the relationship between the dynamic architectural topology of MRA and life within it as key research area, but it remained unclear what this would mean in practice. The following summarises the architectural implications of MRA.



It has been shown how MRA had clear effects on possible architectural topologies. Through their connections across virtual space, virtual adjacencies became possibilities and these could occur in many places at once and change over time. These new forms of adjacencies then resulted in new forms of spatial integration. The spatial integration of connected physical spaces was being changed by inhabitants on the fly as they moved their MRACells in virtual space. This occurred individually but could also take the form of groups when more than two MRACells were brought together. Importantly, these changes could occur for spaces whose spatial integration would not normally be considered, since they were remote from each other. It was then shown that the effects of this integration extended beyond the physical cell, that virtual navigation in MRA could not reduce the already existing spatial integration in an architectural topology and that the spatial integration of each MRACell in MRA was the result of the collective actions of all inhabitants.

The placement of MRA technology was also very important for the understanding of the effect on awareness and social interaction with MRA. Orienting the camera in such a way that no one was permanently in its view, resulted in fewer instances of social interaction at the MRACells concerned. Orienting it so that other interfaces were in view allowed others to make judgements about the activities of the inhabitant of that particular MRACell. This was reinforced by the fact that the MRA interface was always at an angle to other interfaces in the space, which in itself resulted in the inhabitant needing to turn towards MRA to be able to use it. This turn was clearly visible to others. The placement in physical space and the resulting orientation to different parts of this space was also very important. Locating the MRA interface in the deep part of a physical space and turning it towards the shallow part encouraged chance encounters between people connecting over MRA and people passing through that particular MRACell. It also provided inhabitants who were attempting to connect, with valuable clues about the state of the wider environment of a particular MRACell. At the same time this now required inhabitants to control access from two different sides of their space, effectively turning it into a corridor. This could be prevented in the other main type of installation with the MRA interface located in the shallow part, pointing to the deep part. However, this supported social interaction at that MRACell less well.

Although the topological limitations of physical space have been eased through MRA, it has also been shown that through the adoption of a three-dimensional spatial framework in virtual space, new limitations had been introduced. Groups of more than four MRACells would have been difficult, if not impossible to establish, especially if an audio connection had been a requirement. In fact, not many group arrangements were recorded, but this should not be attributed to geometry alone. There were only six MRACells overall, which made larger groups relatively unlikely in itself. There was also no overall control over the topology, so that groups could only ever be established through individual decisions resulting in a communal configuration. Also, the uses recorded in the vignettes did not suggest that inhabitants ever had the desire to meet in larger groups.

Finally, change in MRA was topological and controlled by its inhabitants. Certain unspoken norms and rules emerged over time regarding the acceptable architectural configurations in MRA. The fact that remaining in the audio range of other inhabitants without being seen, passing through their MRACell, and passing through their closed virtual front, were all deemed unacceptable, resulted in relatively widely spaced configurations, with the MRACell in good visual contact but outside audio range. Inhabitants tended to bring their MRACells closer together for more focussed social interaction, pulling back out of audio range once these had ended.

#### **10.1.4 Life in MRA**

For a description of life within MRA, three categories of participants were introduced: core inhabitants, permanent inhabitants and visitors. These different groups were shown to play very different roles in the use of MRA. In summary, it can be said that inhabitants of MRA took control of the MRA topology, actively re-configuring it according to their needs. This then impacted directly on the possible encounters within MRA, between and among the different groups of people using MRA. It was also shown that people collaborated directly in the use of the MRA interface and that there were different ownership relations between them and the MRACell that they were currently using.

Inhabitants had a number of motivations for interacting with and within MRA. They used it to keep aware of activities in remote spaces, of the overall state of

the MRA topology and of activities in virtual space. This could be done actively by reconfiguring MRA, for example to make oneself aware of a certain event. However, once configured it also allowed inhabitants to be more passively aware of any interaction within their range. Verbal social interaction fell into three categories, which were also influenced by each other. There were arranged meetings, social interactions that were deliberately initiated by one of the inhabitants, and chance encounters. Notably, chance encounters across MRA occurred in physical space rather than in virtual space and were entirely dependent on the existing architectural configuration. Another major motivation to interact with the MRA itself was to control the privacy settings of each of the MRACells. Inhabitants virtually relocated their MRACells so as to not be disturbed or overheard by others and so as not to disturb or overhear others. The privacy settings of the MRACells were used in a similar fashion. However, their effect on others was somewhat more direct, as MRACells became completely unavailable for social interaction when closed, rather than just being out of the way and slightly more difficult to reach. Some additional but less important motivations were the re-configuration of MRA for others, the use of MRA as a technology demonstrator and the use of MRA as prop for local interaction.

In terms of social networks in MRA, it can be said that MRA supported the already existing social network over distance very well, helped to strengthen it and managed to extend it, although in a very limited way. MRA was used for interaction very much in an occasioned, purposeful way. Once there was a social connection with someone or there was a requirement to work together, MRA greatly facilitated the resulting interaction.

#### **10.1.5 MRA topology – Social interaction**

Finally, it is worth returning to the relationship between the dynamic architectural topology of MRA and social interaction taking place within it. It has already been discussed how social rules shaped the emerging topology. It is also clear how the resulting topology then affected social interaction, one example being chance encounters. In fact, the conclusion that can be drawn at this point based on the material presented so far is that social interaction within MRA and its dynamic architectural topology were inextricably intertwined. It is clear that inhabitants did not separate interacting across MRA from interacting with others

in physical space. Social interaction took place across the whole MRA topology, where it moved seamlessly between the two domains and where the topology was continuously adjusted to suit the individual requirements of its inhabitants. This was because the MRA topology itself was embedded within the general physical topology of everyday social interaction that people occupied and moved through. The material presented in Vignettes 5 and 7 reinforces this point.

Vignette 5 shows how inhabitants were able to manage and move between multiple social interactions taking place within the MRA topology (see section 8.1.2.e). These interactions could occur exclusively in physical space, for example in a single MRACell. They could occur across two physical spaces remote from each other, either linked by MRA or by another communication technology like the telephone for example. Multiple interactions could also occur within the virtual space of MRA itself. Inhabitants managed these by separating them in time, in space, or simply by letting them continue in parallel with each other. Clearly though, inhabitants had no problems moving between those activities whether they were local or remote across the MRA or indeed across a different communication technology. Vignette 7 shows a whole series of social interactions triggered by people's physical and virtual movement through the MRA topology (see section 8.1.2.g). People passing through their respective local spaces became available to inhabitants of MRA as soon as they entered the MRA topology. First of all they were available to people physically present in that particular MRACell. They also made themselves available to others who were currently connected over the MRA.

Equally, people reconfiguring MRA made themselves available to anyone present in the MRACell to which they were connected as well as to the people physically co-present with them, an issue powerfully demonstrated in Vignette 6, where Sarah and Fred explore the MRA topology collaboratively (see section 8.1.2.f). Episodes of social interaction within 'reach' of any one of the MRACells can therefore not really be separated into those that happen within physical space and those that happen in MRA. The above then leads to the understanding that social interaction within MRA and its dynamic architectural topology are linked in a fundamental way: social interaction drives its reconfiguration and the resulting topology in turn influences social interaction.

### 10.1.6 Cognition in MRA

The final section of the discussion chapter has then explored environmental cognition within Mixed Reality Architecture. 'Embodied-Embedded' cognition, a relatively recent approach has briefly been contrasted with the representational and connectionist perspectives. As one of its main premises, 'Embodied-embedded' cognition advocates the view that the brain, body and environment cannot be described separately when analysing cognition. This reflection has been prompted by studying MRA. The long-term use of MRA has resulted in certain patterns of use to emerge, which meant that for all its inhabitants the MRA as a whole acted as an extension of the environment into virtual space and into remote physical space. In addition, the MRACell acted as an extension to the body into virtual space, particularly during virtual navigation, but this second effect was reserved mainly for core inhabitants. Inhabitants have been observed to cope smoothly with stimuli from both the physical and the virtual parts of MRA and it has been argued that a design that supports this ability is crucial for the everyday use of any Mixed Reality system.

The shape of such a cognitive space can then be described as adhering to a three-dimensional Euclidean metric in the immediate surrounding of a person in Mixed Reality, with other parts of the overall configuration becoming mainly configurationally relevant, whether they are physical or virtual, just like in purely physical architectural configurations. Finally, as the use of Mixed Reality type environments become more widespread and based on the findings of the different patterns of use found in MRA, it has been argued that environmental cognition as a field needs to make space for digital extensions of our bodies and environments as a permanent feature in its conceptual framework.

## *10.2 Outlook*

The final section of this thesis is concerned with providing an outlook on the possible future uses of MRA. The long term study of MRA has shown its promise in being deployed in organisations that are flexible and spatially distributed. In this situation MRA has been shown to support well the needs for formal and informal social interaction between members of distributed teams. In general, this would apply to commercial and non-commercial organisations that depend on creative

team work, such as universities, design firms, laboratories or indeed architecture firms, where the ability to share a three-dimensional space might well be useful in collaborative design or review work.

The technical implementation of MRA is comparatively simple and its installation cost per MRACell is in the region of a good video conferencing node. Currently, MRA is stable but does need daily input from an administrator to deal with the occasional software problem, network disconnections and patches to the system software on host machines. For a longer term non-research deployment the underlying software would benefit from a new implementation. This should deal with a better interface to authoring and administration. It would also be beneficial to improve the scalability of MRA and the way the underlying MASSIVE3 software deals with networking disconnections. Beyond these more technical issues it is worth briefly considering what might need to be done to make a wider deployment of MRA succeed in terms of its effect on social interaction between distributed team members.

### **10.2.1 Social networks**

It has already been shown that MRA is well suited for maintaining and strengthening existing social networks. It has also been shown that it can lead to new social networks, although this is comparatively rare. Of course, creating new social connections does not necessarily have to be the aim of linking remote physical spaces. It could just be that the aim is to support existing social groups and any additional connections are a bonus. In such an instance, the sites would either have to be very carefully chosen or imposed, which might conceivably occur for links that are installed in commercial settings. This type of selection of suitable groups to connect has of course been suggested previously in the Media Space literature (Dourish and Bly, 1992) (Fish, et al, 1990). In such cases the requirement to work together will most likely increase the use of an always-on connection between participating physical sites.

There might be other measures that could be taken. During the main study of MRA no efforts were made to actively enlarge the social network beyond the features that have been designed into MRA and the occasional introduction of inhabitants to each other. It can only be speculated that more formal introductions of people to each other and perhaps staged group events would have

resulted in more social interaction between people not previously known to each other. As Hillier has argued, rituals, as one might call such organised events, can be used to 'overcome spatial separation and reinforce relationships that are not naturally made in the everyday spatial domain' (Hillier, 1996). However it still seems relatively unlikely that this in itself would have changed matters substantially because it would possibly not have given people a broad enough basis of subjects to talk about at their next encounter.

If the enlargement of social networks through the establishment of new social contacts is the goal, there are however other measures that can be directly derived from the findings of study 2. Some conclusions can be drawn in terms of installing MRACells in such a way that the potential for social interaction is increased with the hope that this might over time increase the size of the social network. These measures are concerned with the groups of people to install MRACells with, the location of the interface in the linked spaces and the overall size of the MRA.

### **Groups of people**

The majority of MRACells should be installed in spaces that are controlled by individuals or by a very small group of people (i.e. not more than three or four for an office space). This would ensure that their requirements regarding privacy and awareness do not clash too often and their own social networks do not clash too severely either. For example, there might be people that one inhabitant would like to be in contact with, who another inhabitant of that same MRACell might like to avoid. Semi-public spaces like the Bartlett and MRL MRACell showed another problem with larger numbers of inhabitants, in that they did not provide enough privacy for either their inhabitants or others who connected to them. It is not suggested here that public and semi-public spaces should be disregarded completely but simply that social interaction will be less frequent and less intensive.

At the same time, the number of occupants of a space is not the only factor that needs to be considered. Single offices often belong to people higher up in the organisational hierarchy. As has been mentioned previously, they are therefore often located in the deeper, less integrated parts of a building. Making such an office part of an MRACell, potentially increases its level of integration beyond what its occupants are willing to tolerate. If they then close their MRACell to de-

crease the risk of being spatially more integrated and therefore more accessible, they affect all others and reduce the potential for social interaction.

In summary, the key might be the connection of individuals or small groups of people located in reasonably private offices, who have a vested interest themselves in being connected and being contacted by others in an MRA. For example, on a collaborative project it would be a matter of connecting people who deal with and are involved in the day to day work, rather than their supervisors who are likely to be involved in many other activities and generally attempt to control the level of access to them quite tightly. Coming back to the original argument, the above measures are unlikely to directly increase the social network, but this effect might be more indirect, simply through a larger proportion of MRACells being available to others more frequently resulting in a higher potential for encounters.

### **Location**

It has already been discussed that the location of the MRA interface within a connected space has a clear effect on interaction at a given MRACell. The orientation towards other inhabitants in that space and the orientation to other interfaces need to be considered. Most importantly, the orientation to the environment clearly affects the type of social interaction. To increase the likelihood of social interaction, an installation in the deep part of a space facing the shallow part, will allow others who are connecting to this MRACell more opportunities to encounter more people, in addition to giving them a greater sense of the remote environment in general.

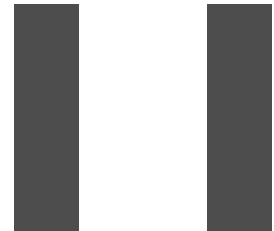
### **Overall size of MRA**

Finally, the overall size of MRA and related to that the overall number of MRACells should be increased. At a certain threshold, it simply becomes likely that there is 'somebody for everybody'. This would allow for sub-groups of people to be established. It would also allow for an MRA environment large and anonymous enough to allow one to avoid others who are connected, instead of not using the MRA at all. It is believed that a number of 20 MRACells in selected physical locations would deliver the necessary increase in density, while with another increase in magnitude the number should be sufficient to require less selection, especially if new MRACells could be based on a referral system.



### 10.2.2 The use of MRA as prototyping tool

Finally, a slightly different use of MRA might also be interesting to explore. This would be made possible through increase in the physical mobility of the MRACell interface equipment. Beyond simply making it easier to decide on the best physical location within a chosen physical space, MRA could be used as a prototyping tool to test out potential new social networks before commitments are made to changes to the building fabric. It can be imagined that this might be used in the planning phase of an organisation being restructured. Merging groups of people and the required relocations could be tried with MRA installed between the different parts. Either MRA is then sufficient to support the new, closer working relationship, or a physical relocation is still necessary, which can then be executed with more confidence that it will actually be the right thing to do. Equally, where the re-location of people has already been decided on, their exact spatial relationship in the new or adapted building could be tested. As has been argued right at the outset, architecture has a clear effect on patterns of co-presence and architecture is frequently a reflection of the norms and rules of the society inhabiting it. In contrast to architectural structures that evolve over time, the conscious design of architecture requires the architect to express this relationship in the building plan. Being able to prototype some key aspects of this, not normally possible with something as large and involved as architecture, must clearly be an advantage.



## Appendix

## *11.1 Presenting in Mixed Reality*

### **11.1.1 Schedule of events**

Listed below is a detailed schedule of events during the pilot study including the time codes recorded on the video material:

*Before the formal start [0:00:00:00]*

One researcher introduced the experiments and explained the functionality of the Mixed Reality Boundary to people in the local physical space. The other researcher did the same in remote physical space.

*During the start-up phase [0:00:43:00]*

Before the experiments formally started, an interesting dialogue evolved when people were trying to determine the identity of the virtual participants. Likewise virtual participants discussed the identity of physical participants. The virtual speaker did not realise that the set-up had not finished and began talking twice. The researcher in local physical space took care to align virtual users to ensure they are not blocking the view or are invisible behind some of the geometry. He then gave the go ahead for the first part of the presentation from local physical space. The other researcher gave her o.k. from remote physical space.

*During the virtual presentation [0:16:51:00]*

The virtual speaker presented his talk including virtual slides to the audience. His slides did not update, which meant that he had to resort to hand-written notes as well as a separate computer screen. He moved his HMD up to glance out under it at the notes. His in-experience with navigation using the trackers meant that the researcher in remote physical space had to assist him navigating in certain instances. Both of these problems were not apparent on the other side of the boundary. It appeared that the virtual speaker faced towards the slides instead of facing the audiences. He also seemed to erratically move across the screen. Why that was, was not discussed between speaker and audiences.

*During the virtual question and answer session [0:31:47:00]*

Questions were asked from a physical participant as well as a virtual participant.

*The change of the architecture [0:40:01:01]*

The local researcher prompted the end of the first part of the experiments. The remote researcher triggered the change of the virtual architecture. The local researcher prompted people to allow him to change the physical architecture and changed it.

*During the physical presentation [0:42:10:05]*

The physical speaker presented his talk including physical slides projected on a screen behind him. He changed the slides using a remote control. Virtual participants mentioned to the speaker that they cannot read the slides properly apart from the headings. The physical speaker addresses both parts of the audience equally.

*During the physical question and answer session [0:54:00:0] to [0:58:00:0]*

A number of questions were asked by different participants.

### 11.1.2 Semi-structured Interview Schedule

#### I. What is people's spatial awareness like for virtual and physical spaces?

1. *How often do you play computer games?*
2. *Do you use 3d environments for work (not asked as such but result of discussion)?*
3. *Do you find them easy to navigate?*
4. *Could you please draw a map of the layout of the experiments including virtual and physical spaces*
5. *Could you please draw a map of Nottingham with the following five landmarks: Castle, Victoria Centre, Hockley, Train station, Nottingham Uni old Campus*
6. *Do you find it easy to navigate in a city you visit for the first time?*

#### II. What is people's attitude towards the Mixed Reality Boundary?

1. *Would you consider using the Mixed Reality Boundary for Social interaction? (Communicate with a friend living far away for example)*
2. *How would you say does the Mixed Reality Boundary compare to the Phone?*
3. *Would you have the MRB installed at home?*
4. *Would you have the MRB installed at your work place?*

#### III. Architecture

1. *Did the two spaces appear as separate, as extensions of each other, as one coherent space?*
2. *Was the spatial layout suitable for both: presentations and Q&A sessions?*
3. *Did you understand the change of the topology of the architecture and why it changed?*
4. *Did that help you navigate?*

#### IV. Awareness

1. *Were you aware whether others could see you across the boundary?*
2. *Could you see the other participants at all times across the boundary?*
3. *Could you see the material presented at all times?*

### 11.1.3 Coding scheme and coded data

ID	01 SEX	02 AGE	03 ROLE	04 AFFI	05 OCC	06 LANG	07 PROB
Question No							
Affiliation Occupation Language of problems unique for that participant							
Codes	male = 1 female = 2		audience member virtual = 1 audience member physical = 2 speaker virtual = 3 speaker physical = 4	CRG=1 MRL=2 none=3	In IT = 1 outside IT = 2	English = 1 German = 2	slides did not update = 2 none = 1
0	1	20	2	3	2	1	1
0	2	20	2	3	2	1	1
0	3	29	2	2	1	1	1
0	4	44	2	3	1	2	1
0	5	28	3	2	1	1	2
0	6	28	1	1	1	1	2
0	7	34	1	1	1	1	1
0	8	30	1	1	1	1	1
0	9	28	1	3	2	2	1
Frequency Count							
1	7		4	3	6	7	7
2	2		4	2	3	2	2
3			1	4			
4							
5							
6							
7							
8							
9							
10							
Missing / No response	0	0	0	0	0	0	0
N/A, not asked	0	0	0	0	0	0	0
don't know response	0	0	0	0	0	0	0

08 FR3D	09 3DWO	10a EANAVE	10b VNAVMEH	10c PEANADEP	11a EANANC	11b PNAVMEH	11c PEANADEP
i.1	i.2	i.3			i.6		
How often do you play computer games	Do you use 3d environments for work ( not asked as such but result of discussion)?	Do you find them easy to navigate ? Multiple answers possible	Methods for navigating mentioned? Multiple answers possible	Ease of navigation depends on (reported)? Multiple answers possible	Do you find it easy to navigate in a city you visit for the first time?	How do you navigate? Multiple answers possible.	What does it depend on?
never=1, once a month=2, once a week=3, a couple of times a week=4, used to play, familiar with them=5	yes=1, no=2	easy=1 quite easy=2 with difficulties=3	use of landmarks =1 mental model =2 same way as in real buildings = 3 maps =4	depends on quality of environment = 1 depends on quality of the interface = 2	easy = 1 quite easy = 2 quite difficult = 3 difficult = 4	use of landmarks = 1 use of maps = 2 use of signs = 3 use of routes = 4 use of mental model = 5 stay in known area = 6	depends on mode of transport = 1 reliance on others - others present, more difficult = 2
4	2	2	99	99	2	5	99
4	2	2	1	99	2	1	99
2	1	1	99	99	1	2	99
1	1	3	0	99	2	2	99
1	1	2	99	99	1	2	99
4	1	3	1	99	2	1	3
5	1	2	4	99	0	0	0
3	1	2	1	3	4	99	99
1	2	0	99	99	1	2	99
3	6	1	3	0	3	3	0
1	3	5	0	1	4	3	0
1		2	0	0	0	0	2
3		0	1	0	1	0	1
1						1	0
						0	1
0	0	0	4	8	0	1	5
0	0	1	1	0	1	1	1
0	0	0	0	0	0	0	0



12a MRBSOC	12b MRBSOCCON	12c MRBSOCCOM	13 MRBPHONE
II.1 Would you consider the MRB for social interaction ?	Conditions mentioned	Other comments	II.2 How does the MRB compare to the phone ? Multiple answers possible
yes = 1 yes, under certain circumstances = 2 no = 3	reliability = 1 no replacement for face-face = 2 application dependent = 3 not for deep emotions = 4 needs better video = 5	loss of eye contact and facial expression = 1 preference of telephone and video conferencing over MRB = 2 distractions in local physical space = 3 familiarisation with new technology = 4	adds common space = 1 no disadvantage = 6 adds human expression = 2 phone is more private = 7 adds closeness = 3 adds ability to look at objects = 4 more fun = 9 does not add anything = 5 MRB between phone and face to face = 10
2	2	99	0
2	1	99	9
2	99	99	99
2	3	4	6
2	5	1	2
2	99	99	3
2	2	3	7
2	99	2	1
2	3	99	1
2	2	4	5
2	3	99	99
0	1	2	
9	3	1	2
2	2	1	1
0	1	1	0
1	0		1
			1
			1
			0
			1
			0
			1
			0
0	2	6	0
0	0	0	1
0	0	0	0

14a MRBATHOME	14b MRBATHOUS	14c MRBATHOCO	15a MRBATWORK	15b MRBATWOUS	15c MRBATWOCO
II.3 Would you have the Mixed Reality Boundary installed at home ?	Uses	Conditions	II.4 Would you have it installed at the work place?	Uses	Concerns
yes = 1 may be = 2 no = 3	recreation = 1 communication = 2 community building = 3 work = 4	reliability = 1 aesthetics = 2 practicality = 3 privacy = 4 cost = 5	yes = 1 may be = 2 no = 3	group support = 1 education = 2 access remote space = 3	reliability = 1 ease of use = 2 privacy = 3 abstraction of avatars = 4 free choice = 5
1	99	99	99	1	99
1	99	99	99	2	99
1	99	99	99	1	99
3	0	0	0	1	2
1	1	2	99	1	99
2	4	99	3	2	0
1	2	3	99	2	99
1	99	99	5	1	3
1	2	99	99	2	2
7	1	0	5	2	1
1	2	1	4	1	1
1	0	1	0	1	1
	1	0			1
		1	1		1
0	4	6	0	4	4
0	1	1	0	1	0
0	0	0	0	0	0

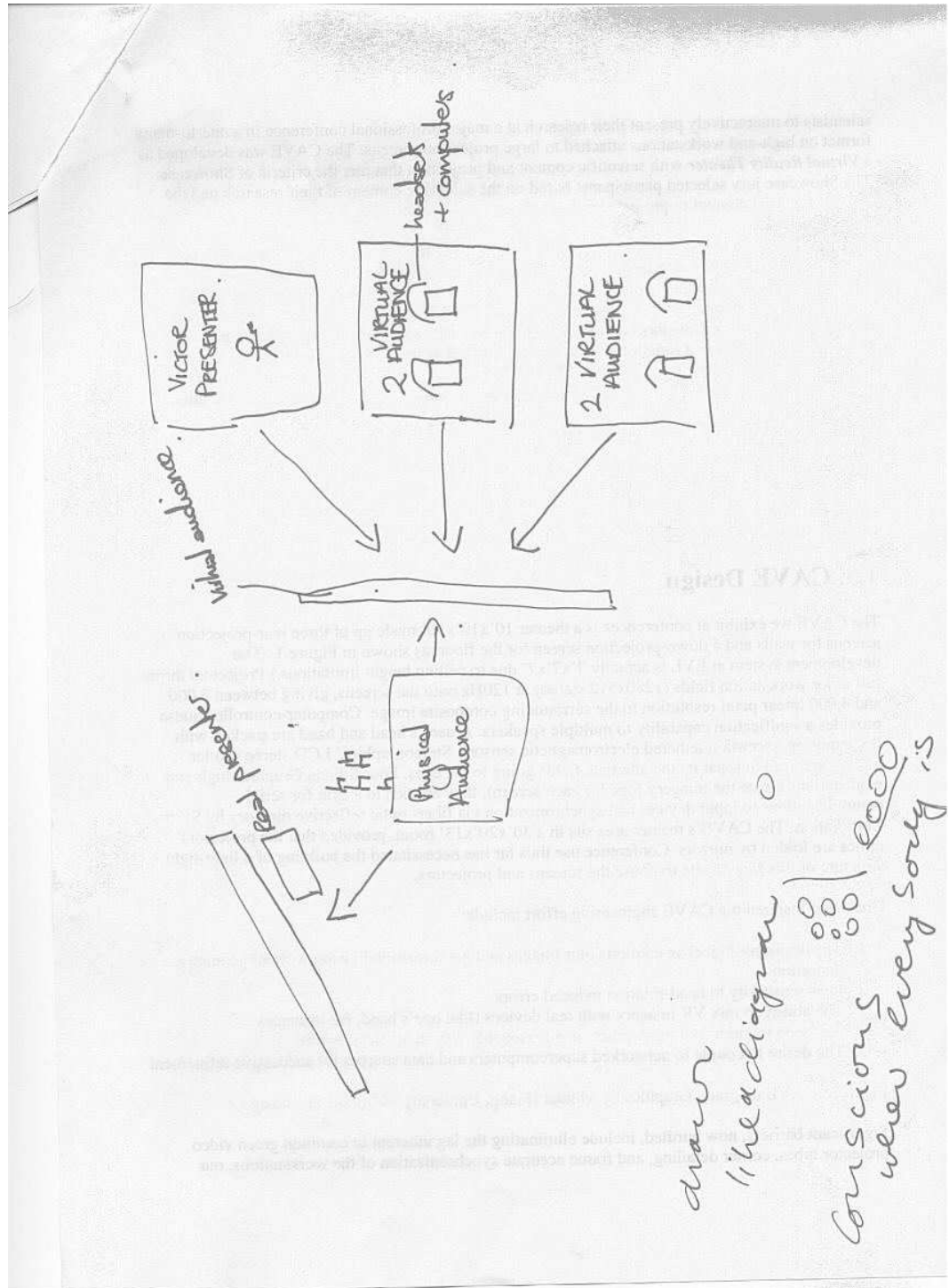
16a SPATR	16b SPASTRQU	16c LOCPAR	17a SPASTSU	17b SPASTSUCCO	18 UNCHTO	19 HELPNV
III.1 Did the two spaces appear as separate, as extensions of each other, answer as one coherent space?	Qualification of previous answer	Physical location of virtual participants	III.2 Was the spatial layout suitable for both: presentations and Q&A sessions ?	Comments	III.3 Did you understand the change of the topology of the architecture and why it changed?	III.4 Did that help you navigate ?
separate = 1 extensions of each other = 2 one coherent = 3 more integrated when presentation was on the side of the participant = 4 more integrated when presentation was on other side of the MRB = 5 depends on application = 6	technology influences integration adversely = 1 environment plays role = 2 the more alike environments are the more coherent the set-up would appear = 3	participants were in same physical location = 1 participants were in separate physical locations = 2	suitable = 1 not suitable = 2 neither good nor bad = 3 works for virtual presentation, not for physical = 4	comparison to physical space = 1 architectural suggestions = 2 technical problems =	yes = 1 no = 2 missed change = 3 does not recall change = 4	yes = 1 no = 2 fold where to go / fairly obvious = 3
1 99	3	1	99	99	1	0
3 99	2	2	4	2	1	0
4 99	99	99	1	99	2	0
2 99	99	99	1	99	1	0
1 99	1	99	1	1	3	0
2 99	1	99	3	1	3	3
3 4	99	99	1	2	4	0
1 99	1	99	1	3	1	2
2 99	99	99	1	3	1	1
3 0	3	1	6	2	5	1
3 0	1	1	0	2	1	1
2 0	1	0	1	2	2	1
1 1			1		1	
0 0						
0 0	1					
0 8	4	7	1	3	0	0
0 0	0	0	0	0	0	6
0 0	0	0	0	0	0	0

20a AWAAC	20 b AWAACCO	21a AWAOP	21b AWAOPCO	22a PVCLEAR	22b PPCLEAR	22c PCOM
IV. 1 Were you aware whether others could see you across the boundary?	Comments	IV.2 Could you see the other participants at all times across the boundary?	Comments	IV.3 Virtual presentation was clear	Physical Presentation was clear	Comments
yes = 1 no = 2 clear for vr speaker, not so clear for ph speaker = 3 not sure = 4	layout helped = 1 initial discussion clarified = 2 assumption of being visible = 3	yes = 1 not at all times = 2 no = 3 knew that they were there = 4	quality of the video = 1 virtual participants moved out of screen = 2 layout was the problem = 3	yes = 1 no = 2	yes = 1 no = 2	material was not clear = 1 slides at unsuitable angle = 2
1	99	2	99	2	99	1
3	99	4	99	2	99	1
1	2	2	99	2	99	2
1	1	2	2	1	1	99
1	99	1	1	0	2	1
1	99	2	3	99	2	1
4	3	2	99	1	2	1
1	2	2	3	1	2	99
2	99	2	1	1	2	99
6	1	1	2	4	1	5
1	2	7	1	3	5	1
1	1	0	2			
1		1				
0	5	0	4	1	3	3
0	0	0	0	1	0	0
0	0	0	0	0	0	0

#### 11.1.4 Sketch maps

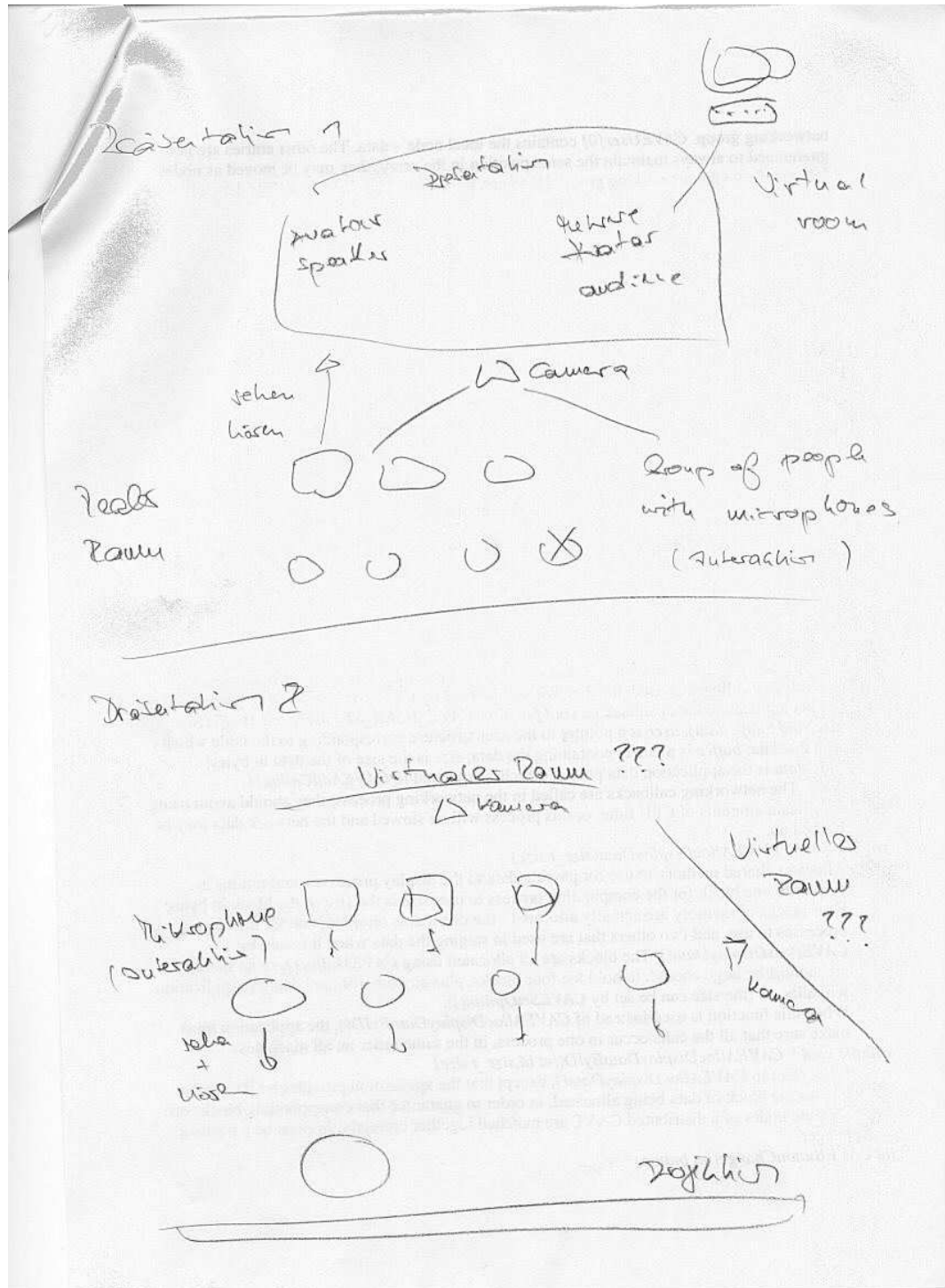
##### Participant 3

Physical audience member



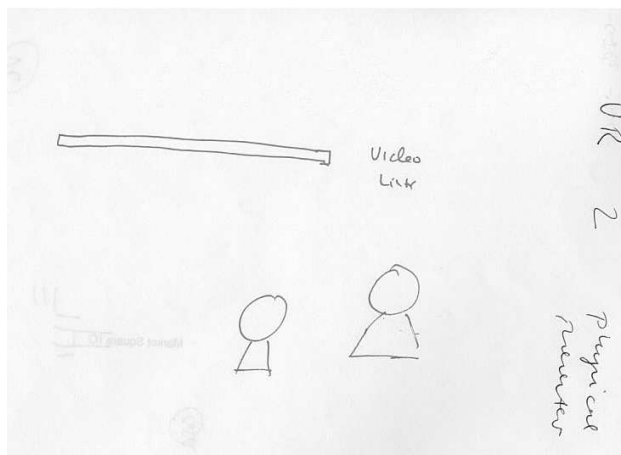
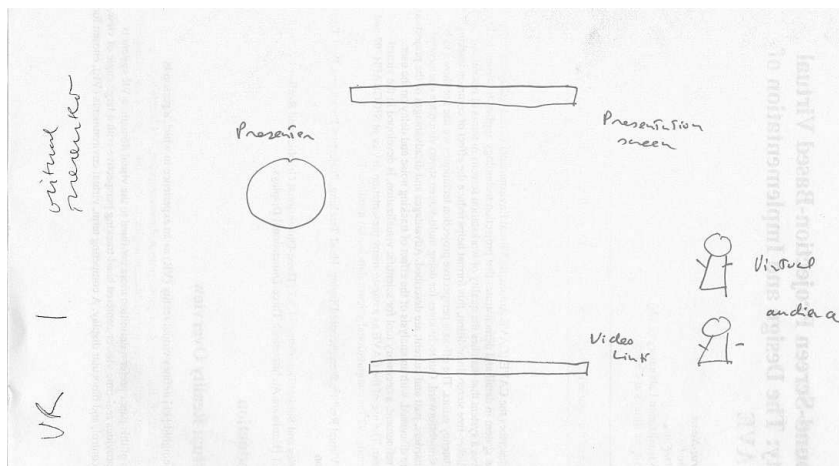
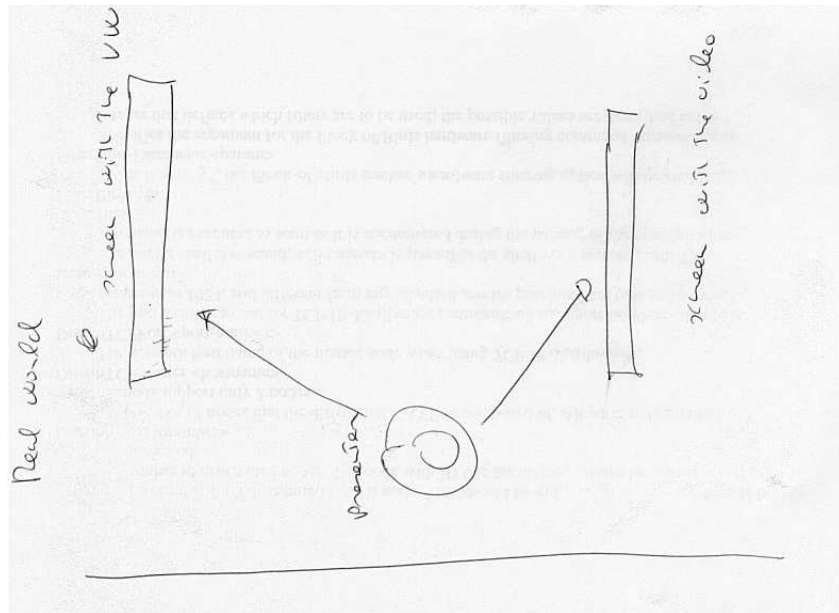
#### Participant 4

Physical audience member



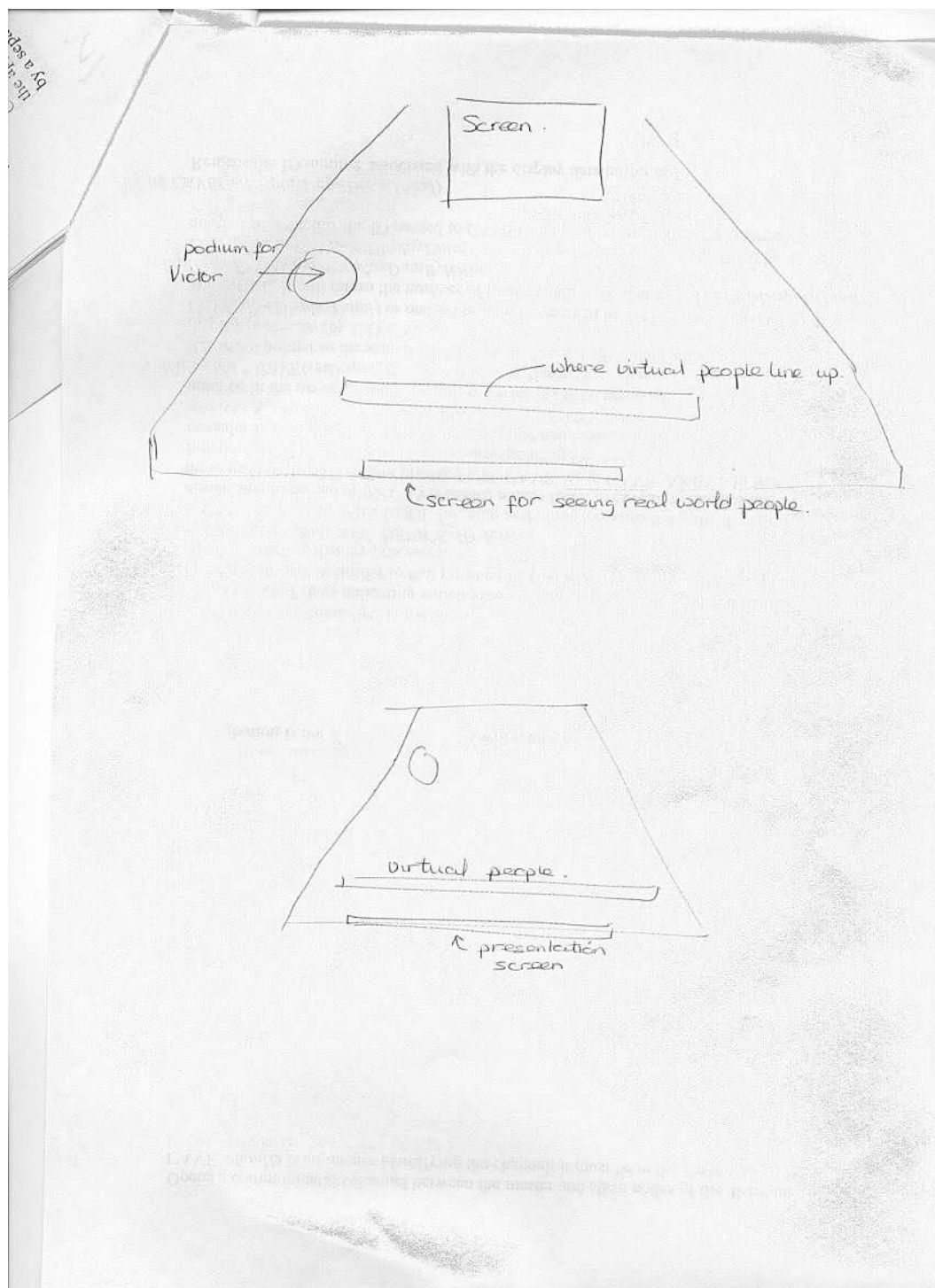
## Participant 5

Virtual speaker



## Participant 6

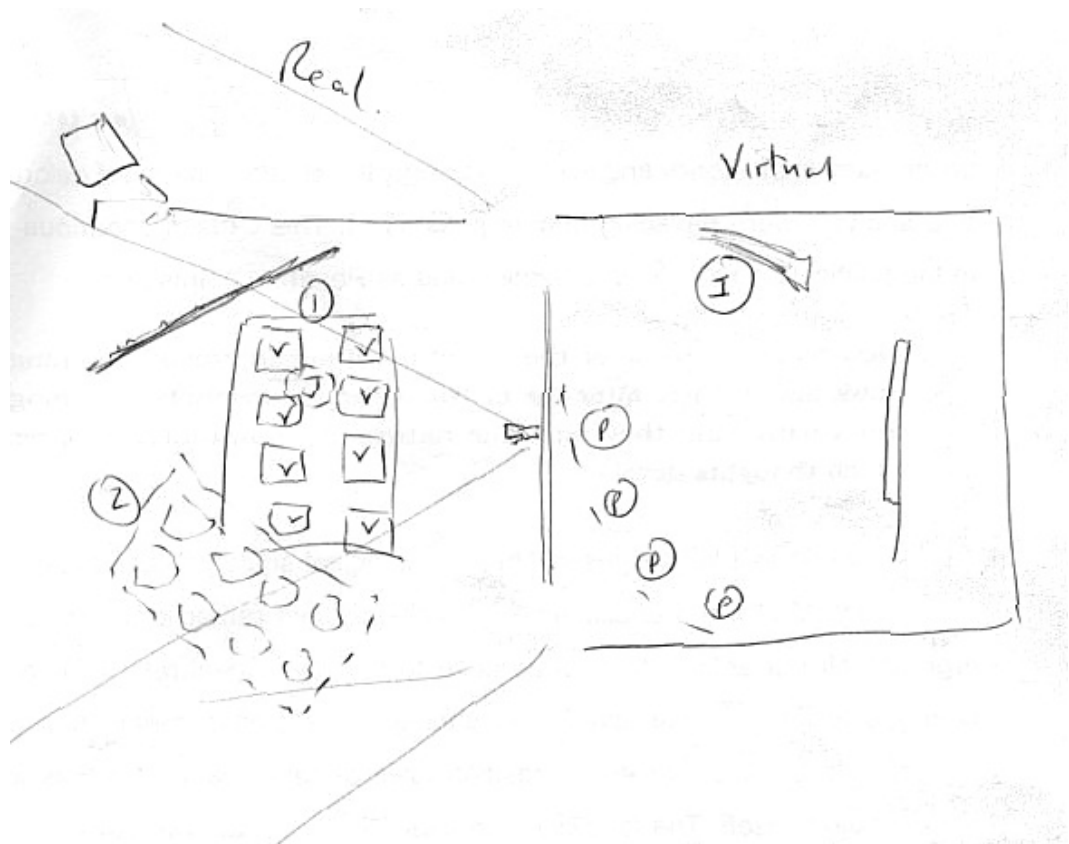
Virtual audience member





**Participant 7**  
Virtual audience member

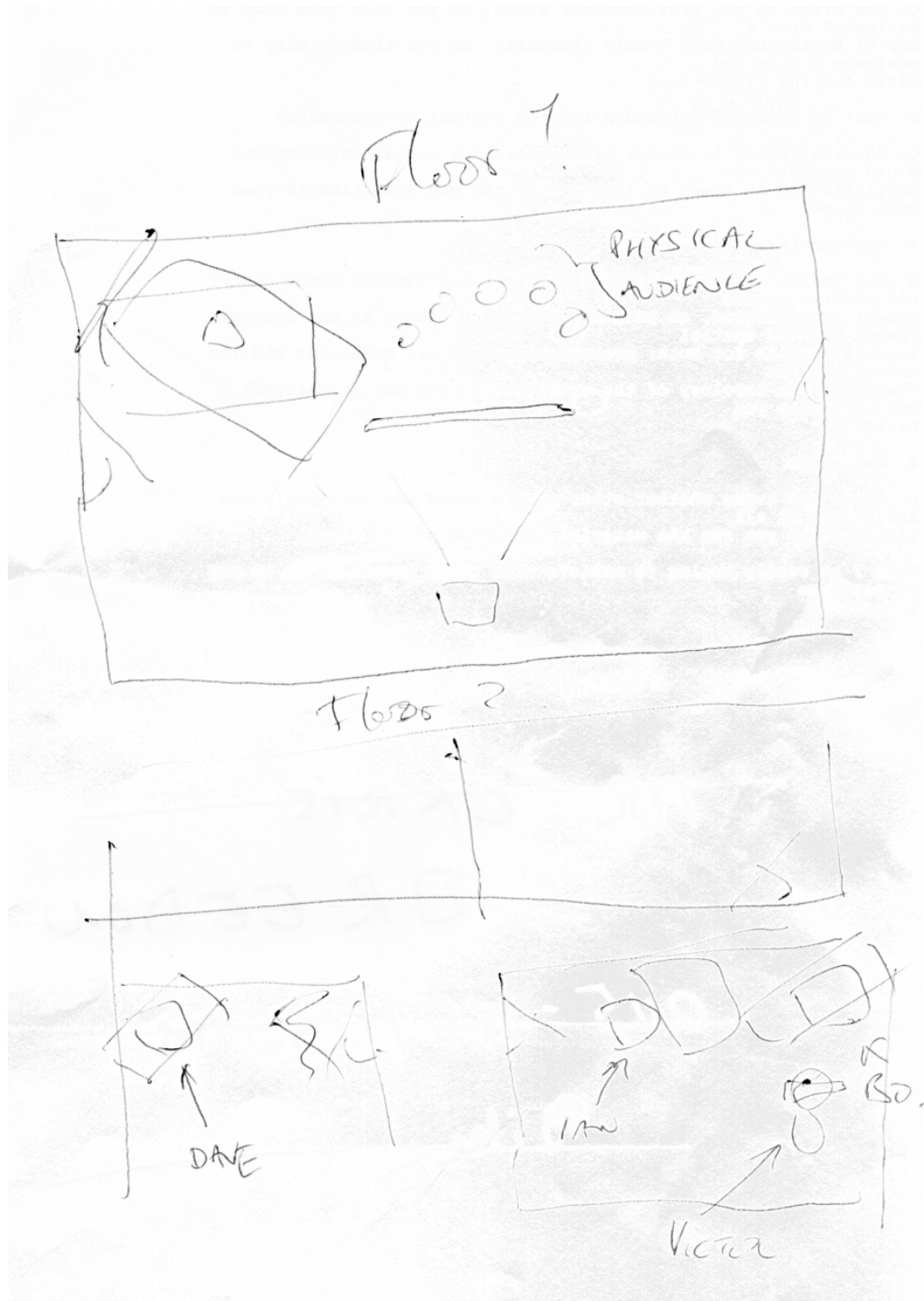
Virtual audience member



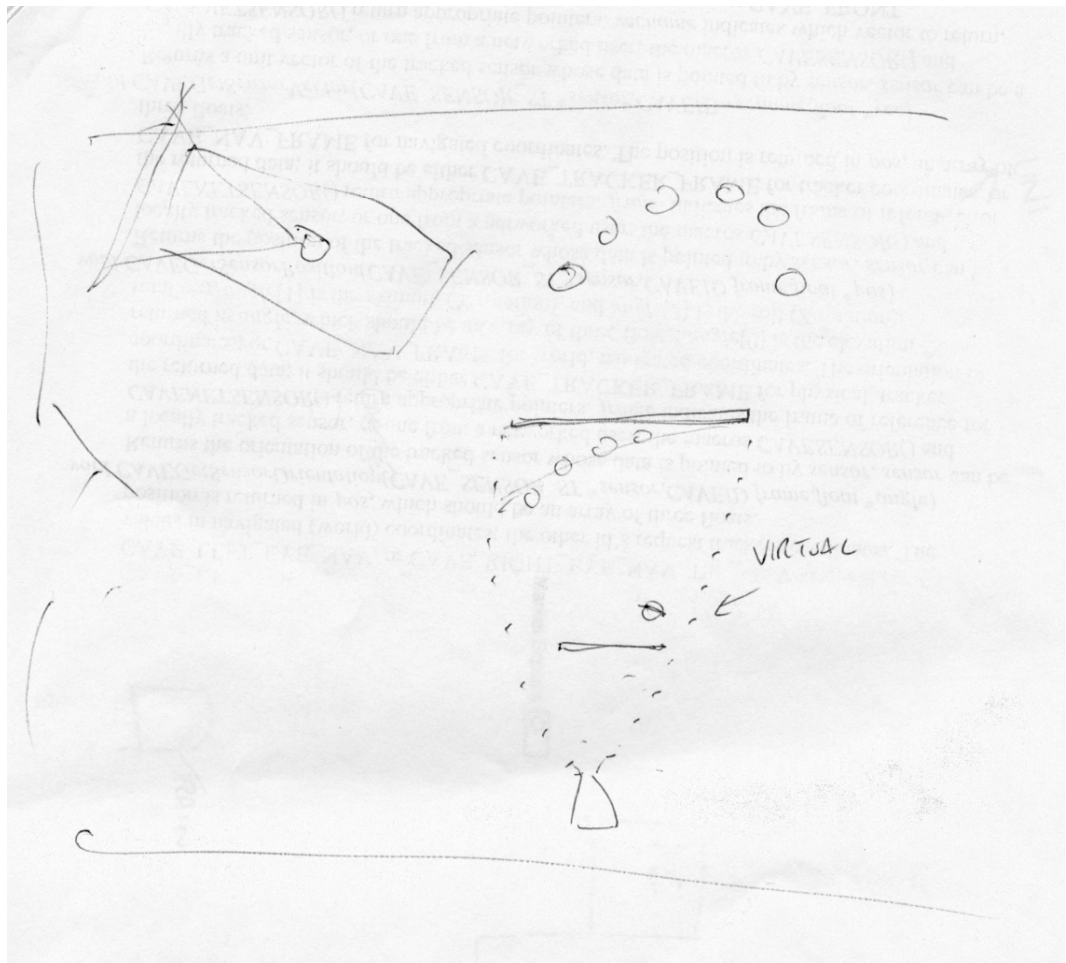
## Participant 8

Virtual audience member

Original map drawn:



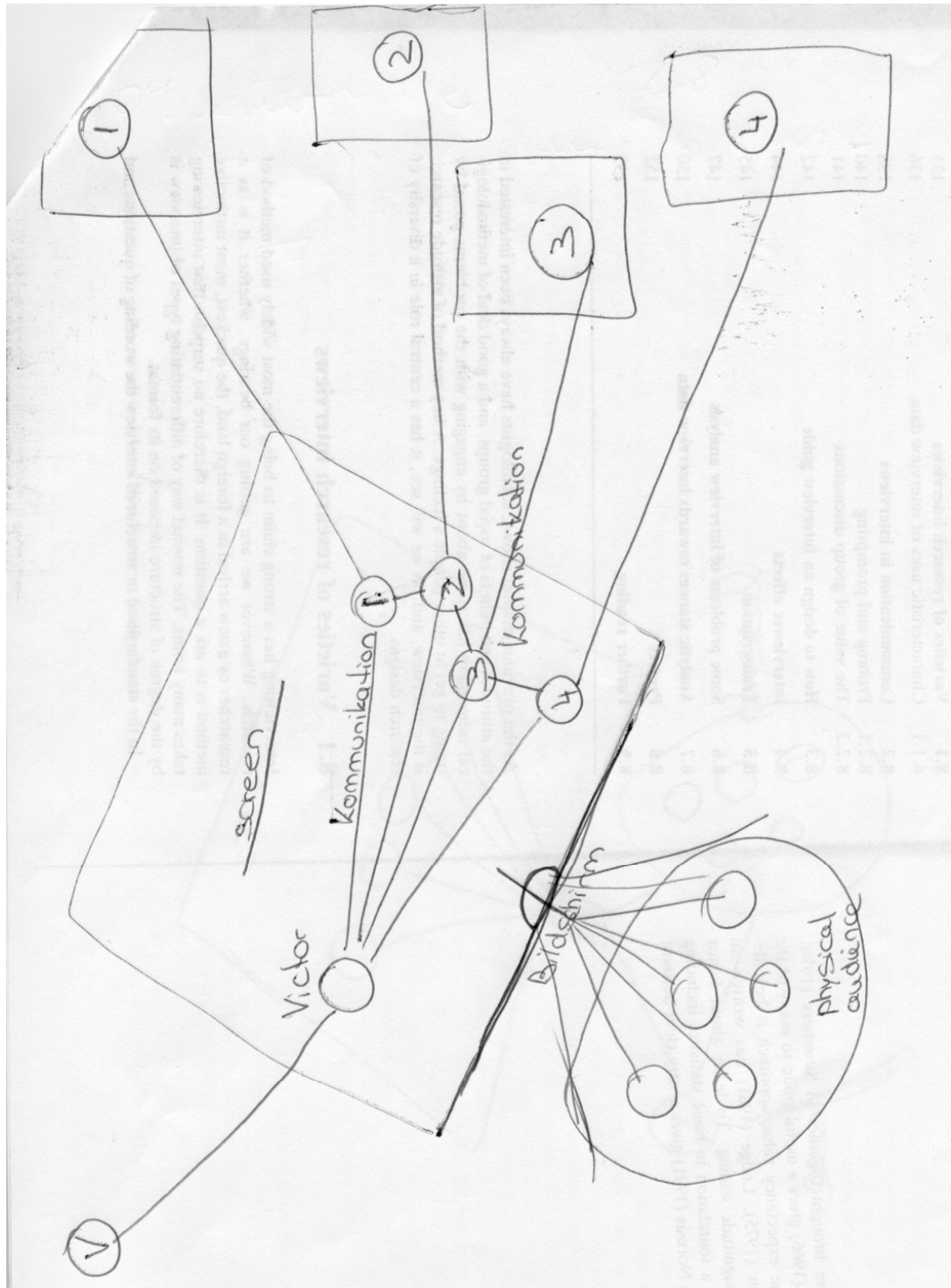
When prompted about the lack of virtual space, participant 8 drew the following map:



## Participant 9

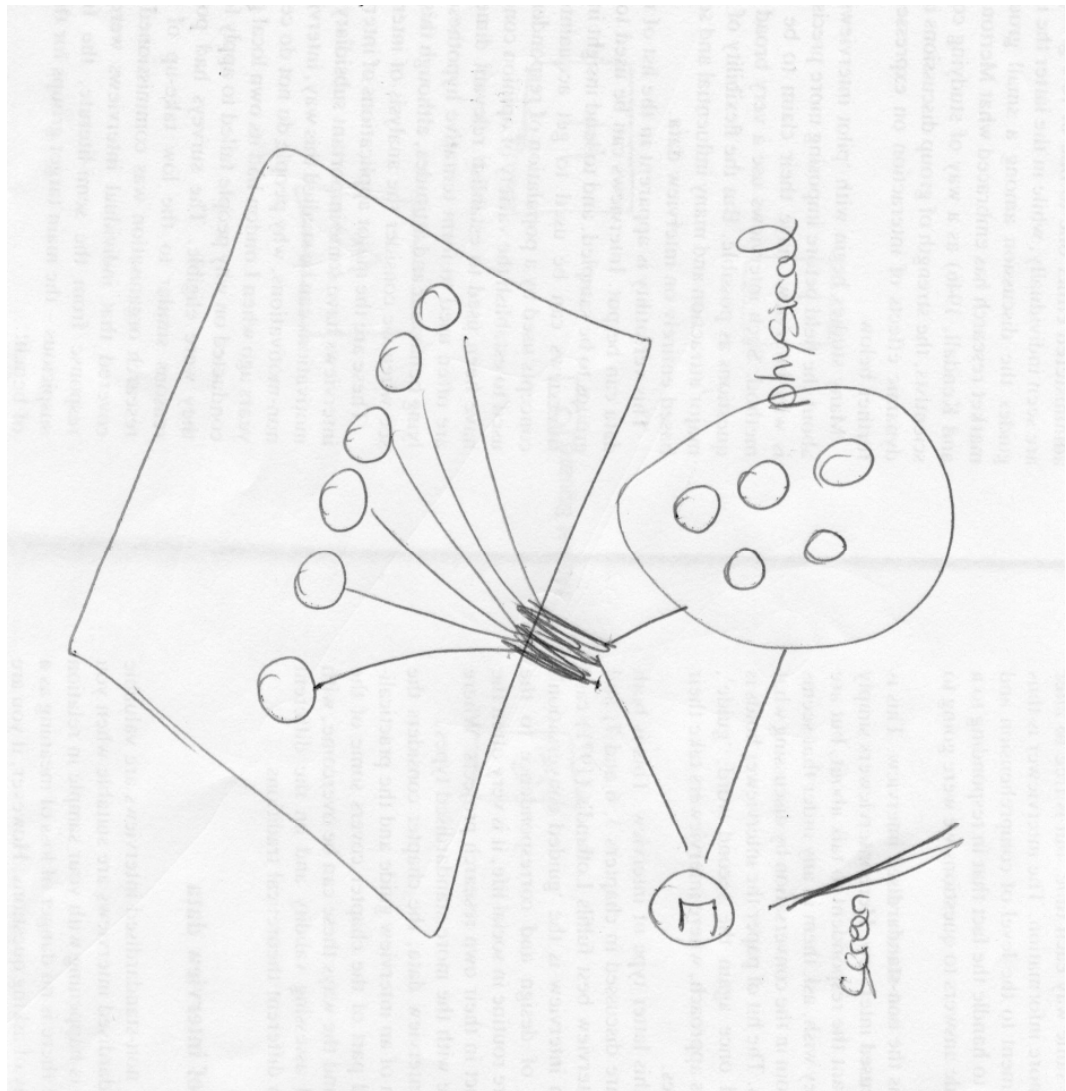
Virtual audience member

Map for virtual presentation:



Physical speaker

Map for physical presentation



## 11.2 Mixed Reality Architecture

### 11.2.1 Interview Survey

Sheet 1	Subject	Before MRA	After MRA	Date
---------	---------	------------	-----------	------

**1. Could you please list the people who you regularly encounter outside arranged meetings or informally at work? Please do this for a typical day during the last month and list 10 people.**


For anonymity, this list will be kept separate from the information you provide later. You are also welcome to list people by their initials only.



[illegible]



Sheet 4	Subject	Before MRA	After MRA
---------	---------	------------	-----------

4. Could you please also list the people you could see a benefit being in contact with for work but do not meet informally or not as often as you would want. These people do not have to be from this site.


For anonymity, this list will be kept separate from the information you provide later. You are also welcome to list people by their initials only.

[illegible]

## 11.2.2 MRA Guide

The guide was presented as double sided A4 colour sheet. Here it has been scaled.

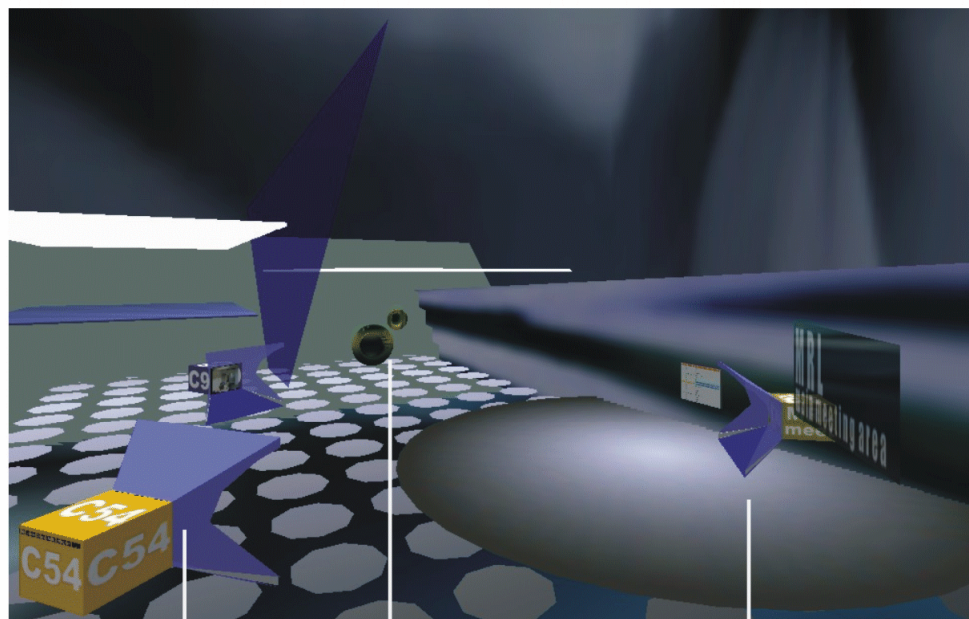
### 11.2.2.a Front Page

## Guide to Mixed Reality Architecture

Mixed Reality Architecture (MRA) allows you to configure your work environment by changing the spatial relationship between your office and other offices/public spaces connected to the system. Your office is one of the Mixed Reality Architectural Cells (MRACell) that are linked by live video and audio across the same public virtual space .

This space as it appears projected in your office is illustrated in the graphic below. There are a number of MRACells located in different parts of the environment. The MRACell associated with the MRL meeting room is located in one corner with the board for announcements and slides right beside it. The opposite corner provides a quieter area away from the main public space and the space next to that contains the radio.

Using the joystick you can move your MRACell to any place within public virtual space that suits your requirements. Using buttons 6 and 8 on the joystick base you can fly up and down (See overleaf for more options).



Radio

Another MRACell

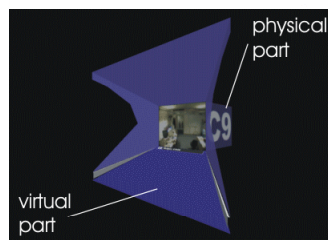
MRL meeting room MRACell  
and board for announcements

Please contact Holger Schnädelbach (hms@cs.nott.ac.uk) with any comments and suggestions.

### 11.2.2.b Back Page

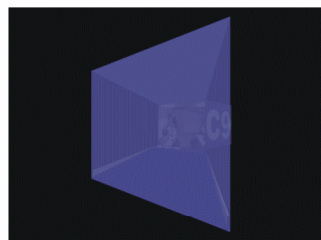
Each MRACell consists of two parts. Its physical part is an office or public space (i.e. meeting room) and is represented in the MRA as a box with the appropriate video texture mapped to its front. Its virtual part extends into MRA and takes on different shapes as controlled by the inhabitants of the corresponding physical space.

By moving around within MRA you can configure how much you can see and hear of other MRACells and events. In addition to that you can toggle the level of visual privacy by changing the appearance of your MRACell by using buttons 5 and 7 on your joystick base (This has no effect on the audio levels).



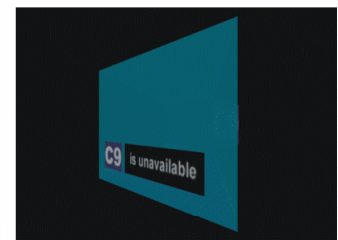
A:  
Open

Live video from your MRACell is available to everyone close by.



B:  
Semi-private

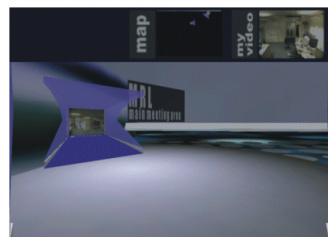
Live video from your MRACell is only fully available to people entering your MRACell.



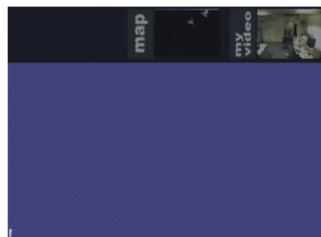
C:  
Unavailable

Live video from your MRACell is switched off.

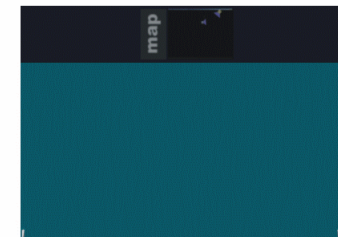
While the above figures show an external view of an MRACell as seen by other inhabitants the corresponding images below represent what you see from your MRACell.



D:



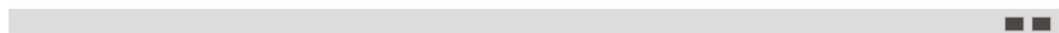
E:



F:

Figure D shows a view into the public virtual space from one of the MRACells. A map in the centre of the top edge of the screen shows the location of all the MRACells currently connected. Live video from your camera is shown in the top right. Figures E and F show the view into the public virtual space after different privacy settings have been applied.

Movement in the public virtual space of the MRA (see the following page) and the privacy settings 'Open', 'Semi-private' and 'Unavailable' taken together are a useful tool to indicate to others in the MRA to what extent you are willing to participate in any conversation.



### 11.2.3 Vignettes

What follows is a listing of the vignettes produced from the observational study. Vignette 1 has been included in full in the methodology section. The following presents vignettes 2 to 9.

### 11.2.3.a Vignette 2 – Chance encounters and awareness

Date	Start time	Duration
26/10/2004	10:38:57	3 min 40 sec


#### Context

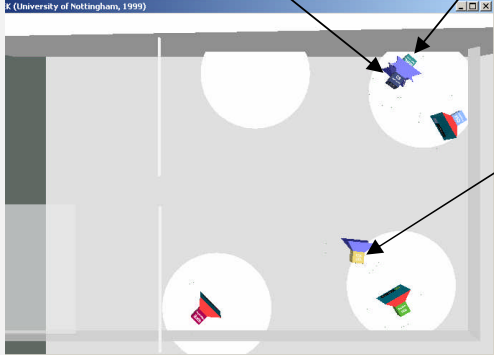
This vignette comprises two different interactions. The first is a chance encounter at the public MRL MRACell, when Sam (SH) ‘catches’ Gavin (GT) walking past and involves him in a conversation. The second directly following on from the first is when Gavin navigates around in the MRA to discover that Scott (SA) is busy and discusses this with Sam.

#### Vignette


Initially, the Bath, Bartlett and C54 MRACells are closed, set back and play no further role in this vignette. The 127C MRACell is open and Scott is working at his desk. The C9 MRACell is also open with Sam in the process of moving it towards the open MRL MRACell. After talking to Scott, Sam pulls the C9 MRACell away from 127C, waving into the camera. Scott remains in place, while Sam moves the C9 MRACell over close to the MRL MRACell. At that point, Gavin enters the MRL through the main door, while Sam is still glancing at the screen.

Time	10:38:57		
Room	C9	MRI	127C
People	SH	GT	SA





Sam then initiates a conversation with Gavin.

Time	10:39:11		
Room	C9	MRL	
People	SH	TG	
			

1	SH	Hello there.	Pulling closer to camera Facing screen, holds JS
2	GT	How are you doing?	
3	SH	Has anyone turned up yet?	
4	GT	There is one or two people around, yes.	
5	SH	OK, ... are they hiding?	
6	GT	There is not that many, not really? (laughing)	
7	SH	Ah, OK.	
8	GT	It's two, I think, two of [us.	
9	SH	[It's funny when Dave and Hazel aren't there	
10		and nobody walks through the corridor	
11		much,...the lights keep turning off, so I just	
12		get this completely dark MRL from up here.	
13		(laughing)	
14	GT	It's a nightmare when Dave doesn't turn up,	Repositioning of MRACell
15		because you have to walk all the way round to	
16		get in. [(laughing). Hm, (inaudible)	
17	SH	[Yeah true, yeah.	
18	GT	How's ... How's things with you, anyway ...?	
19	SH	Good.	
20	GT	[ (inaudible)	
21	SH	[ I am recording again, so you are on camera!	
22		Wey [ hey!	
23	GT	[No You haven't (inaudible) my consent.	
24	SH	Ah, I am sure I have (laughing)	
25	GT	No, no (laughing)	Holding hand in front of face
26	SH	(laughing) No, no (laughing)	
27	GT	It's not me. My name is aemh Bob.	
28	SH	... Sorry?	
29	GT	My name is Bob.	
30	SH	Bob yes, oh yes Bob, yeah I recognise you	
31		Bob.	
32	GT	How are you doing?	
33	SH	Is it for aeh... short for aehm Jane?	
34	GT	Yes, that's right (laughing)	
35	SH	(laughing)	
36	GT	Very good (laughing)	Re-positioning Re-positioning
37	SH	(laughing) .. Right, [Ok	
38	GT	[How is thesis writing anyway	
39	SH	Sorry?	
40	GT	How is the thesis writing?	
41	SH	Oh! ... Aaaaargghhh	
42	GT	As good as that?	



43	SH	Yeahh, as good as that. I am kind of aehm ..	Re-orientating
44		Uh .. I am kind of aeh, looking at some data	
45		again, just to do the checkpointing .. Adam	
46		has given me that (inaudible) this morning.	
47	GT	Right.	
48	SH	And see whether I can aeh make use of what	
49		I have recorded, but it looks fine, actually	
50	GT	Good.	
51	SH	The good .. the good thing is, the data collec-	
52		tion really works well, I mean I can ... you can	
53		hear stuff, you can see stuff; it works really	
54		well I think.	
55	GT	Good	
56	SH	Hmm	
57	GT	I'll have a wander round	
58	SH	Yeah	
59	GT	See you later	
60	SH	See you later, ... bye, bye.	

Sam moves the C9 MRACell a little, rotating in the direction Gavin is going, then moves back to his desk. Gavin starts navigating in the MRA standing at the JS stand.

Time	10:41:11		
Room	C9	MRL	127C
People	SH	TG	SA

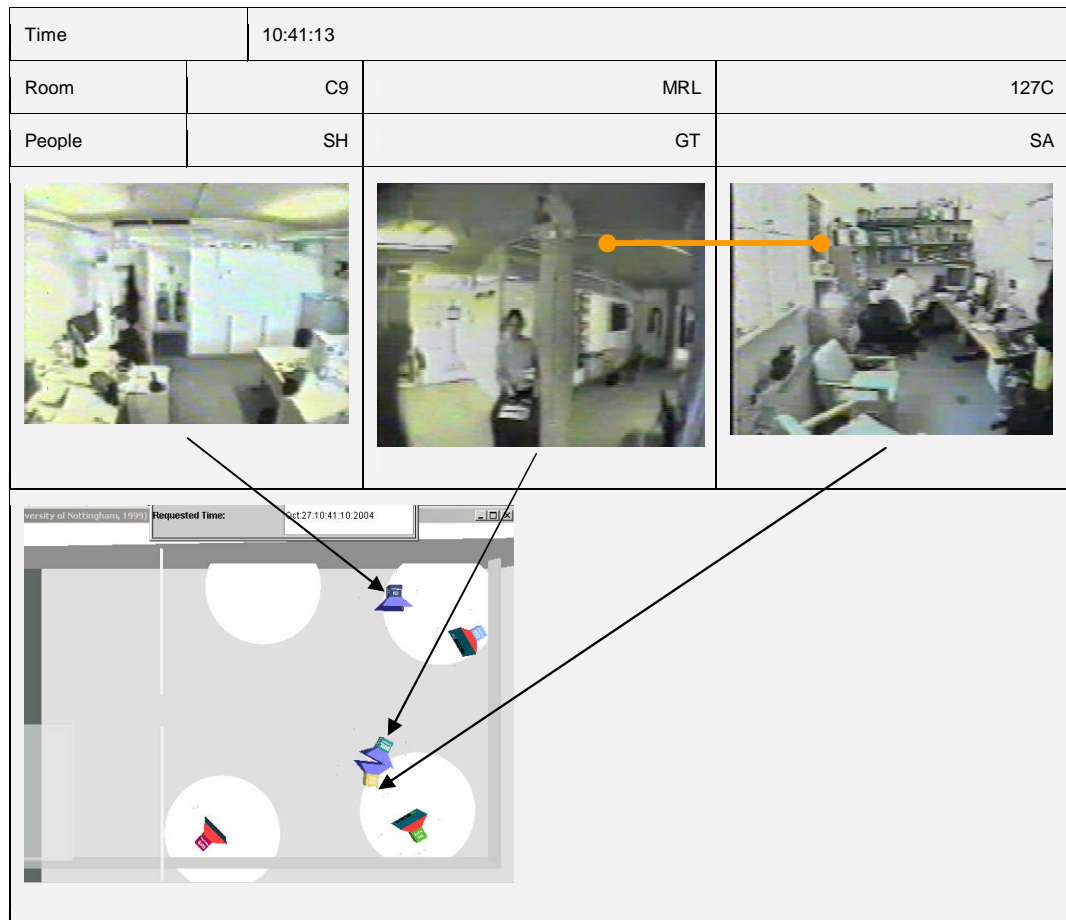







Gavin navigates around in the MRA, glancing into 127C twice, but not saying anything. Scott appears to be unaware of this and continues working at his desk.





Gavin then pulls the MRL MRACell away from 127C, while Sam is looking on. Sam glances at the screen and sets his MRACell to yellow, before opening it again straight away with Gavin navigating in the background. Sam looks up and watches, then sits down still glancing at the screen.

Time	10:42:12		
Room	C9	MRL	127C
People	SH	GT	SA




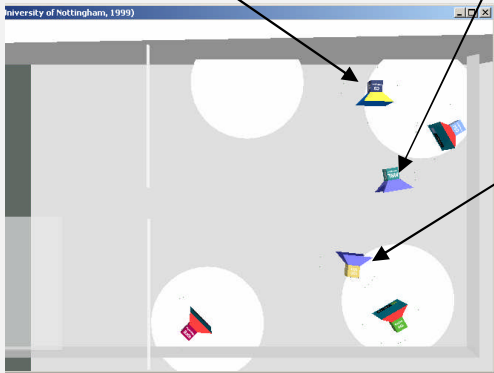




Sam rolls forward in his chair into camera view and starts a conversation.

62	SH	Hello again	
63	GT	Hello (laughing)	
64		[ inaudible	
65	SH	Did you talk,...did you talk to Scott?	
66	GT	No, he looked like he is quite busy, actually.	
67	SH	Yeah, he is eah he is reviewing papers, [ I think	
68	GT	[Oh, dear, Nightmare	
69	SH	hmmm	
70	GT	Anyway, I best get back myself.	
71	SH	OK	
72	GT	See you later	
73	SH	See you later, bye, bye	

Sam gets up, sets the C9 MRACell to yellow and leaves C9. Gavin pulls the MRL MRACell backwards, then turns around, facing away from the C9 MRACell.

Time	10:42:37		
Room	C9	MRL	127C
People		TG	SA
<div></div> <div></div>			

Gavin leaves the MRL foyer to enter the main MRL lab space.

### 11.2.3.b Vignette 3 – Setting up MRA for the meeting



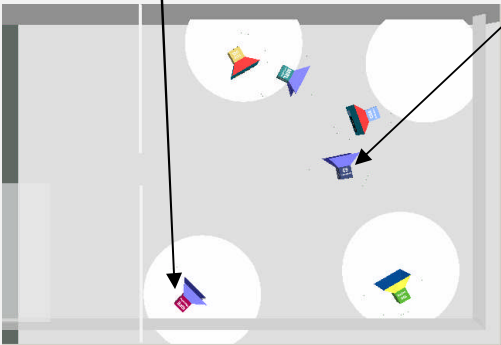
Date	Start time	Duration
29/10/2004	12:39:14	2 min 31 sec

#### Context

In this vignette Sam sets up the MRA for a meeting between Sarah (SD), Karl (KD) and Rico (RT), which has been arranged previously. Karl and Rico are not permanent inhabitants of MRA and are planning to use the C9 MRACell for the meeting. Sam re-configures the MRA to discuss the practicalities with Sarah, as he had not heard from either Karl or Rico. At the end of this interaction, he leaves the C9 MRACell ready, in view of Bath and open, so that the meeting can start smoothly.

#### Vignette

At the outset the C9 and C54 MRACells are arranged as an open quadrangle. C54 is closed. C9 is open with Sam and Beatrice in camera view and Gemma present but outside camera shot. The MRL MRACell is set back slightly, facing this group and Habib appears in camera view sitting on one of the tables. Others are present in the meeting area but cannot be seen. 127C is set back a bit further, set to red (private) and nobody appears in camera view. The Bartlett MRACell is located in one of the corners of the environment, facing all the above MRACells and is set to yellow (semi-private). Finally, the Bath MRACell is located at one of the edges of the environment, open and faces the C9, C54 and MRL MRACells. Sarah is working at her desk there. This vignette only concerns the C9 and Bath MRACells.

Time		12:39:14	
MRACell	Bath	C9	
People	SD	SH, BS	
			
			

Sam is setting up the recording. He walks over to the MASSIVE3 server to make the red dot appear on the map client. This signals to others that a recording is taking place. The dot can be seen to appear on the map. He then checks that audio is coming in with the headphone connected to the recording VHS-S recorder and speaks the time on to tape.

1 2	SH	Twelve-thirty-nine, twenty-ninth of October, two-thousand and four.	Looking at his watch
--------	----	---	----------------------



He takes of the headphones and walks back towards the MASSIVE3 server.

3	SH	That's recording now, as usual	Directed at others in the room
---	----	--------------------------------	--------------------------------

Sam grabs the 'recording notification' notice and fixes it to the outside of the C9 door.

4 5	BS SH	(inaudible) for lunch? Yeah, (inaudible)	
--------	----------	---	--



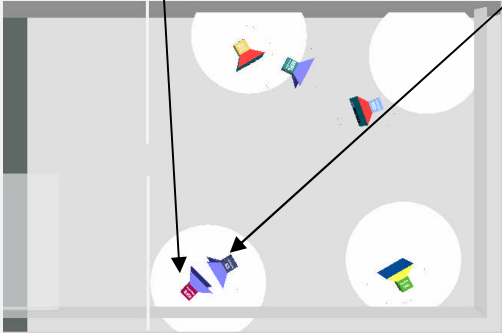
Sam sits down at his desk and then moves forward in to the centre of the camera view. He gets hold of the joystick.

Time	12:39:53		
MRACell	Bath	C9	
People	SD	SH, BS	
			

Sam re-configures the MRA so that the C9 MRACell is brought up close to the Bath MRACell.

6	SH	Hi, Sarah	
---	----	-----------	--

Sarah looks up.

Time		12:40:03	
MRACell	Bath	C9	
People	SD	SH	
			
			

7	SD	Hi there.	Looking at screen.
8	SH	How are you?	
9	SD	... is that Sam?	
10	SH	Yeah, [ hello.	Henry in background
11	SD	[ Oh, hi	
12	SH	Are you meeting again today?	
13	SD	Yes, aeh, do you mind, if I just have a few minutes,	
14		cause I just (inaudible) the document, before I aehm	
15		meet them.	
16	SH	Yeahh, no, no, I .. we are going for lunch now. I don't	
17		know what the other .. guys are doing with the meeting.	
18		They might .. come in here again, I assume.	
19	SD	Oh, do you not heard from them?	
20	SH	[ Aeh	
21	SD	[ Oh, you are recording now? When did you start re-	
22		recording?	
23	SH	A minute ago.	
24	SD	Alright, I need to put up the notice then.	
25	SH	Oh, sorry.	
26	SD	That's alright. Bet, aehm, ok I'll wait and see, if they ap-	
27		pear.	
28	SH	Yeah, ok.	
29	SD	Ok. See you in a minute.	
30	SH	See you in a minute.	
31	GA	Sam, (inaudible) is she? .. Where is (inaudible) Sarah?	

Sam pulls the C9 MRACell back slightly. Sarah leaves her desk to put up the recording notice on the outside of her door.

32	SH	Sorry	
33	GA	Where is .. Sarah?	
34	SH	In Bath.	
35	GA	Oh (laughing) ) (inaudible)	
36	HJ	(laughing)	
37	SH	Sorry.	
38	GA	Because she said, see you in a minute	
39	SH	Oh, no she was just (laughing)	
40	HJ	(inaudible)	
41	SH	(laughing)	



Sarah has returned to her desk and is working. Sam is re-configuring again and moves the C9 MRACell closer to the Bath MRACell again. Sarah looks up. He gets his coat and Henry leaves the office

42	GA	(inaudible) some times.	
43	SH	Yeah, ... confusing.	

Sam gets back to the joystick.

44	SH	So, Sarah, I just leave it open, yeah we are going for lunch now	
----	----	--	--

Sarah looks up fast. Gemma is leaving.

Time		12:41:11	
MRACell	C9	Bath	
People	SH, GA	SD	
			

45	SD	(inaudible) you gave me a shock there. Yeah, ok, I'll	Waving
46		Speak to a bit later on.	
47	SH	Yeah, speak to you a bit later on. Bye, bye.	Waving

Sam pulls back C9

48	SD	.. Can you move it oh uh shall	Grabs joystick
----	----	--------------------------------	----------------



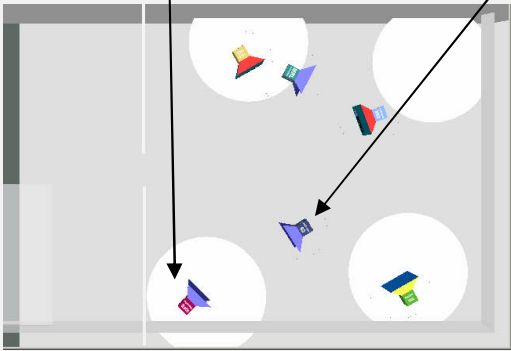
Sarah grabs joystick but does not move. Sam pulls back in

49	SD	, .. can you move it back a little bit?	
50	SH	Yeah I will do, yeah.	
51	SD	Thanks a lot	

Sam pulls away completely, still facing the Bath MRACell, but already out of audio range.

52	SD	See you in a bit.	Waving
----	----	-------------------	--------

Sam is preparing his lunch and then leaves. The physical door is closed and locked, while the MRACell remains set to blue (open).

Time	12:41:45		
MRACell	Bath	C9	
People		SD	
			
			



### 11.2.3.c Vignette 4 – An arranged meeting

Date	Start time	Duration
Friday 29/10/2004	12:53:06	16 min 48 sec




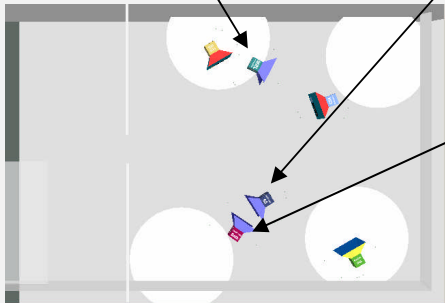
#### Context

Karl (KD), Sarah (SH) and Rico (RT) have agreed to have a PhD tutorial in the MRA. Karl and Rico are not permanent inhabitants of an MRACell and have arranged to use the C9 MRACell instead. On his way to C9, Karl briefly checks out the MRA from the MRL MRACell. He then enters the C9 MRACell and is acknowledged by Sarah. She then moves a little closer.



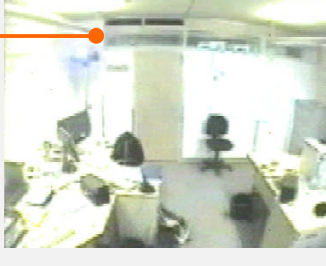
As Rico is not available, the meeting proceeds without him. When the inhabitants of the C9 MRACell, Sam (SH), Gemma (GA) and Beatrice (BS) return from their lunch, the meeting only continues for a little while, before Sarah and Karl agree to attempt the meeting again with Rico about an hour later. After the meeting has finished, Sarah pulls back her MRACell and sets it to red (private).

#### Vignette

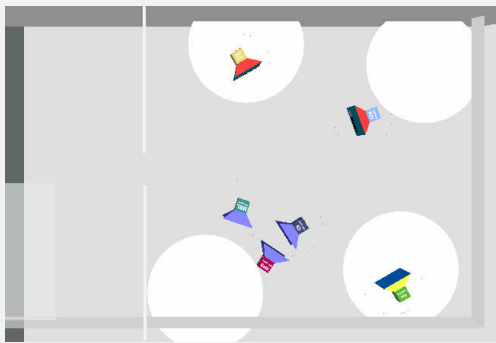
At the outset the 127C and C54 MRACells are set to red (private) and located at one edge of the environment. The Bartlett MRACell is set to yellow (semi-private) and faces the other MRACells. The MRL MRACell is open, located at one edge of the environment and faces C54. Nobody appears in camera view. The C9 and Bath MRACells are both open and are facing each other, with nobody present in C9 and Sarah working at her desk in Bath. It is a Friday, which means the weekly seminar has just taken place and most people are out for lunch in Nottingham. This vignette concerns only the MRL, C9 and Bath MRACells.

Time		12:53:06		
MRACell		MRL	C9	Bath
People				SD
				
				

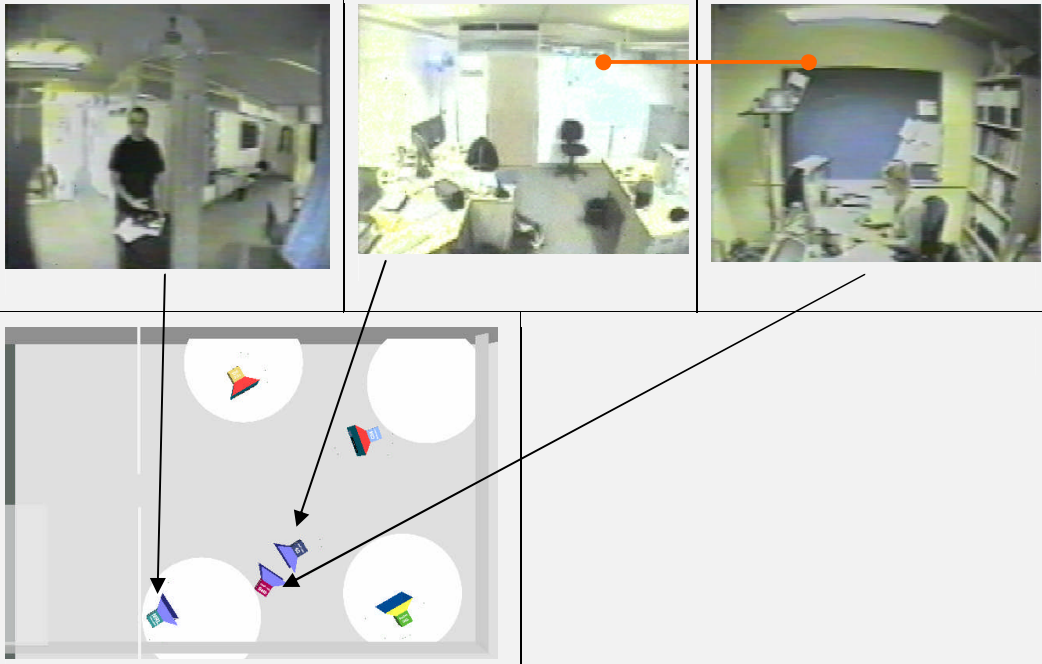
Karl enters the MRL MRACell through the main entrance, walks straight up to the joystick, gets hold of it and starts navigating while looking at the screen. Sarah is typing in her office.

Time	12:53:15		
MRACell	MRL	Bath	
People	KD	SD	
			

Karl turns the MRL MRACell around in the direction of the Bath/C9 group, moves towards them and pauses briefly. He then continues in the same direction but passes by the group. Sarah takes no notice of this movement.

Time	12:53:38		
			


Habib passes through the MRL MRACell, leaving through the main door. Shortly after, Karl pauses briefly and turns round in the direction in which Habib left. He then puts down the paper he is carrying and grabs the joystick with both hands, holding the base with the left hand and steering the top with the right hand. He continues to the edge of the environment, turns around and moves the MRL MRACell back slightly in the direction he came from.

Time	12:54:03		
MRACell	MRL	C9	Bath
People	KD		SD
			


Karl then leaves the MRL MRACell through the main door.

Time	12:54:06		
MRACell	MRL	Bath	C9
People	KD	SD	
			

Sarah remains at her desk in Bath, occasionally checking the MRA screen. Gerald walks through the MRL MRACell, leaves through the main door and closes it. Karl knocks on the door of C9. He knocks again, but this time more forcefully. Sarah looks up.


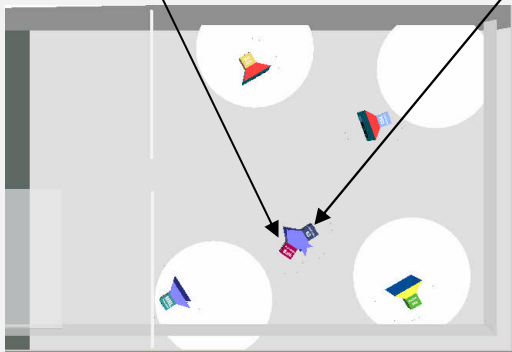
Time	12:55:05		
MRACell	Bath	C9	
People	SD		
			

Keys can be heard, the door to C9 opens and Karl enters. He closes the door behind him.

Time	12:55:19		
MRACell	Bath	C9	
People	SD	KD	
			

1	SD	Oh, hi there.	
2	KD	Hello.	
3	SD	I was just about to reply to your email.	
4	KD	Alright, ok, what were you gonna say?	

Sarah grabs the joystick and moves the Bath MRACell closer.

Time	12:55:23		
MRACell	Bath	C9	
People	SD	KD	
			
			


5	SD	I, I was gonna say, two o'clock is fine .. is that alright with you?	
6			
7	KD	Sorry, what?	
8	SD	Is two o'clock alright with you?	
9	KD	Yeah, that's fine with me, yeah.	
10	SD	Yeah, but if Rico can't make it at two, let's just meet any-	
11		way.	
12	KD	Ok, fair enough	
13	SD	Aehm, because, it's a bit annoying, because I missed	
14		lunch and worked for my paper (inaudible) getting it	
15		sorted for 12:30, so aehm .., if he can't come at two,	
16		rather than delay ..	
17	KD	[ Yeah	
18	SD	[ again it would be easier to just talk about it and we can	
19		catch up, we can catch up with him again for another	
20		boundary meeting when he is free.	
21	KD	Yeah, ok. That sounds good.	
22	SD	Have you actually seen him, have you?	
23	KD	Aehm, yeah he was, he just came in at the end of the	
24		aehm lab meeting, so I spoke to him briefly as he was	
25		kind of like walking away.	
26	SD	(laughing) ... has he forgotten it was today or was it just	
27	KD	No, he knew, it just seems that he's got some other	
28		meetings to do and stuff. He just seems busy.	
29	SD	Alright, ok. (Inaudible) looks fine but if we aehm .. if he	
30		doesn't appear, then lets just go ahead anyway, I have	
31		got a view things, I went, I just quickly went through you	
32		paper this morning, (inaudible) that and I just got a view	
33		comments, we might as well have a chat at two anyway.	

34	KD	Ok .. [ Aehm	Picks up pile of papers
35	SD	[ Alright, see you soon, Oh,	
36	KD	... What I was gonna do .. aehm .. with, aeh what I have	
37		done is, I I have made .. some aeh just .. graphs [ aeh	
38	SD	Alright, [ ok	
39	KD	Do you want me to send them .. to you? Are you [ gonna	
40		have time to look at the results	
41	SD	[ Have you analysed results already?	
42	KD	Kind of, yeah.	
43	SD	Oh, excellent	
44	KD	(laughing). Aeh, do you want the good news?	
45	SD	Yeah, tell me, tell me briefly what the news is, cause then	
46		I will be ready for the meeting, as well. That's good.	
47	KD	Well .. aehm .. I've, I've kind of fiddled and played around	
48		with the numbers a fair bit.	
50	SD	[Yeah	
51	KD	[Aehm .. and I made the decision eventually to .. exclude	
52		one of the girls from the gesture condition .. aehm .. be-	
53		cause we had quite a lot of trouble, when we were trying	
54		to do her session, I had to keep stopping it.	
55	SD	Oh, technical problems?	
56	KD	Yeah, yeah ... [ things going wrong	
57	SD	Ok.	

What follows is a detailed discussion of data and analysis of Karl's current PhD study. The entire discussion is conducted with Karl standing and lasts for just over nine minutes.

58	SD	(Inaudible) that sounds really good, sounds really inter-	
59		esting results.	
60	KD	Yeah. What, aehm, I can't take credit for this because it	
61		was Karen's suggestion .. aehm, but what I could do.	

Keys can be heard in the background in the door to C9. Karl turns around when the door opens. Sarah looks on.

Time		13:07:10		
MRACell		Bath	C9	
People		SD	KD	
				


Gemma (GA), Beatrice (BS) and Sam (SH) enter.

62	KD	Alright, (inaudible) talking, but come in	
63	GA	Can we? (laughing)	
64	SD	Hello	
65	KD	Aehm	
66	GA	Hello	
67	SH	Hello	




68	SD	Hello, [ hi there	
----	----	-------------------	--

They walk towards their desks.

Time	13:07:10		
MRACell	Bath	C9	
People	SD	KD, GA, SH, BS	
			

69	KD	[ What ..	
70	KD	What I might do is [ aeh	
71	SD	[ Oh hi, everybody is coming back from lunch (laughing)	
72	KD	(laughing)	
73	GA	(laughing)	
74	KD	What I might do is I'll, I'll compare the aehm .. the .. the	
75		gestures that Karen used, when she was instructing	
76		them ..	




Beatrice and Gemma have both sat down at their desk. Gemma is outside camera view. Sam picks up some paper work and leaves C9.

Time	13:07:32		
MRACell	Bath	C9	
People	SD	KD, GA, SH, BS	
			

77	SD	[ Yeah	
78	KD	[ (inaudible) experience (inaudible) .. aeh .. with the video	
79		I have taken of them doing the second assembly, second	
80		self-assembly, aeh and then I might be able to find some	
81		clues that .. they are actually ... kind of using	
82	SD	Yeah [ using her gestures	
83	KD	[ movements that she has directly shown them.	
84	SD	Yeah.	

85	KD	And then you can make an argument of what they are	
86		doing is .. re-call memory ..	
87	SD	Yeah.	
88	KD	rather than recognition and that's .. why you get the dif-	
89		ference in time, (inaudible) re-call memory is always	
90		quicker.	
91	SD	Yeah, that sounds a really good idea.	
92	GA	(inaudible)	
93	SD	Did you say that was Karen's idea?	


Beatrice gets up and then leaves C9. Sam appears in the MRL MRACell, grabs the joystick briefly but does not actually move the MRL MRACell and then continues into the main lab. From this view point, he would have seen that the meeting is still ongoing.

Time		13:08:12		
MRACell		Bath	C9	MRL
People		SD	KD, GA, BS	SH
				

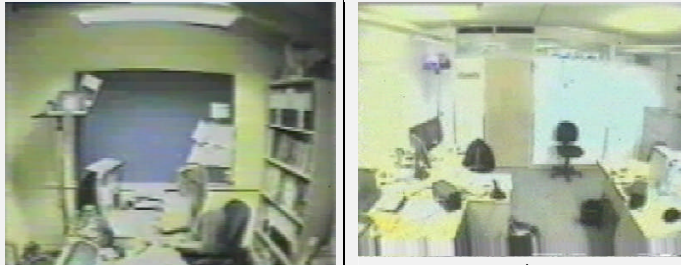
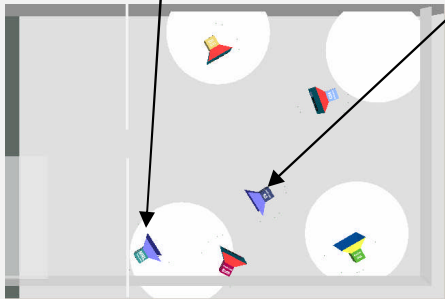
94	KD	Sorry?	Directed at Gemma Looking around
95	SD	Did you say that was Karen's idea?	
96	KD	Yeah, that was Karen's suggestion.	
97	SD	Oh, you are going to get her in (inaudible) your PhD.	
98		(laughing)	
99	KD	Yeah, I (inaudible) whether she'd be interested, frankly.	
100		(laughing).	
101	SD	(laughing) (inaudible), aren't we? (laughing)	
102	KD	Probably, yeah.	
103	SD	(laughing) Oh, no. (laughing).	
104	KD	Ok .. shall I aehm speak to you again at two?	
105	SD	Yeah, it (inaudible) aehm, if you've got the graphs handy,	
106		send them to me, so I can have a quick look at them be-	
107		fore two, but don't worry, if you haven't.	
108	KD	No aehm .. I'll send them now.	
109	SD	Yeah, I (inaudible) quick look through them aehm .. but	
110		that's good, no that's really interesting. . Ok, (inaudible)	
111		through, and we'll catch up again at two.	
112	KD	Ok (inaudible) see you later	
113	SD	See you then	
114	KD	Thanks anyway	
115	GA	(laughing)	
116	KD	(inaudible) my key?	
117	GA	(inaudible)	

Sarah gets hold of the joystick and starts pulling the Bath MRACell back. Karl is making his way out of C9.



Time		13:09:04	
MRACell	Bath	C9	
People	SD	KD, GA	
			

Karl leaves. Sarah is still navigating back, then sets her MRACell to red (private) using the keyboard, puts the joystick down and checks her phone. She talks to someone just outside her office, but then sits back down at her desk.

Time		13:09:54	
MRACell	C9	Bath	
People	GA	SD	
			
			

### 11.2.3.d Vignette 5 – Joining an existing group

Date	Start time	Duration
30/07/2004	15:33:23	8 min 44 sec

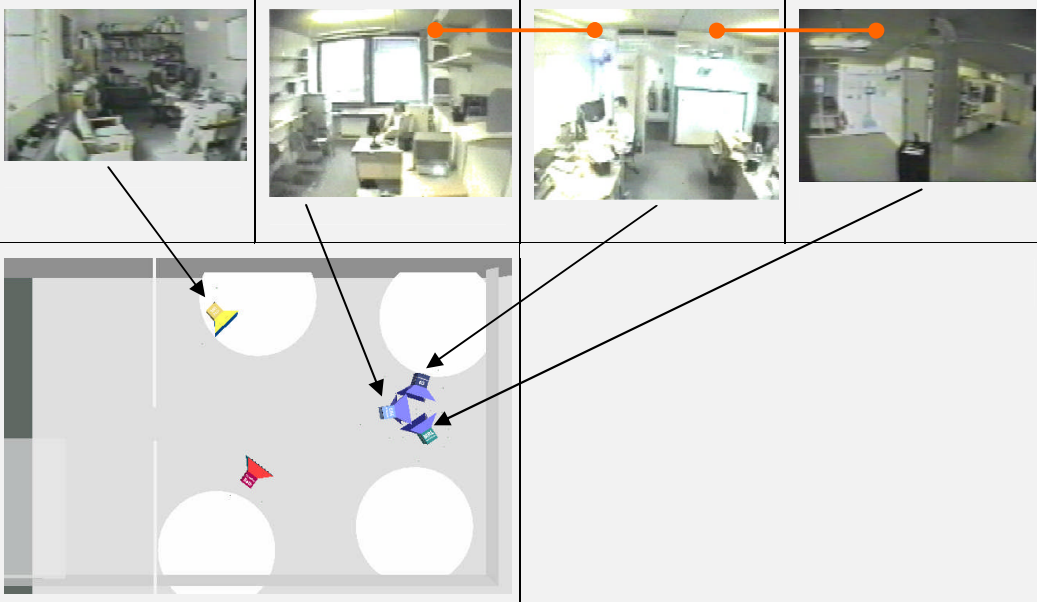
#### Context

This vignette shows Scott (SA) joining but also breaking up an existing group of MRACells when initiating a conversation with Sam (SH). The conversation lasts for several minutes. Scott and Sam talk about the MRA privacy settings and how they have been transgressed, paper reviewing and some technical issues before breaking up the meeting. Shortly after Scott re-links the C9 and 127C MRACells to discuss an additional technical issue before breaking up a final time at the end of the conversation.


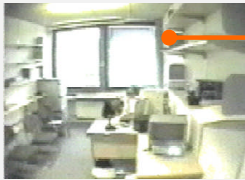


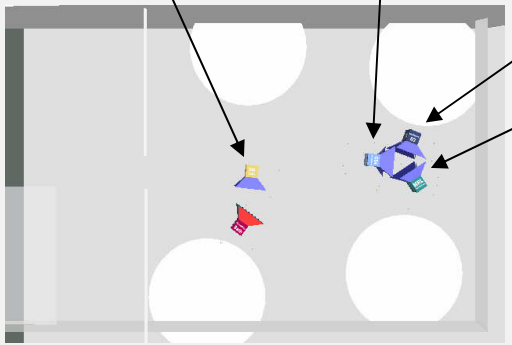
#### Vignette

At the outset, the MRL, C54 and C9 MRACells are arranged in a closed triangle. No one is in view at the MRL, while the doors to Glenda's (GH) and Lance's (LD) office are open and the lights are turned on. Kate (KB) and Sam (SH) are located at their desks in C54 and C9 respectively.

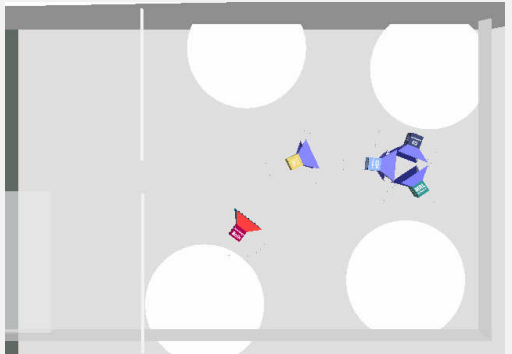
The 127C MRACell is set to semi-private (yellow), sitting back facing the group of three. The Bath MRACell is set to private (red) and also sitting back facing the group but from a different direction. Here Fred (FM) is working at Sarah's (SD) desk. The Bartlett MRACell is off, because of a local power shut down. The interaction in this vignette concerns only the C9, C54, 127C and MRL MRACells.

Time	15:33:23			
Room	127C	C54	C9	MRL
People	SA	KB	SH	
				

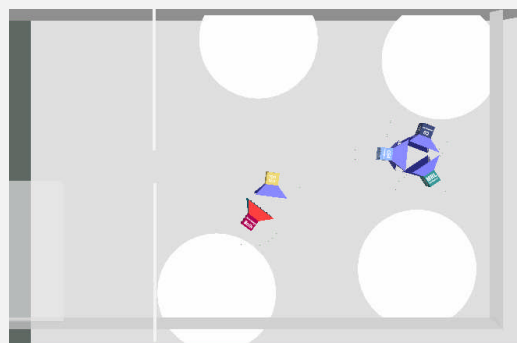
Scott turns around, moves forward with this chair and gets hold of the JS. He starts re-configuring the MRA by first opening the 127C MRACell and moving closer to the Bath MRACell.

Time	15:33:44			
Room	127C	C54	C9	MRL
People	Scott	KB	SH	
				
				

Scott moves into audio range of the Bath MRACell but does not break through the virtual door, then pulls away again and circles around towards the group of three.

Time	15:33:49			
				

Gemma enters C9 with a paper and a cup. Sam turns round towards her desk. Scott moves back towards the Bath MRACell.

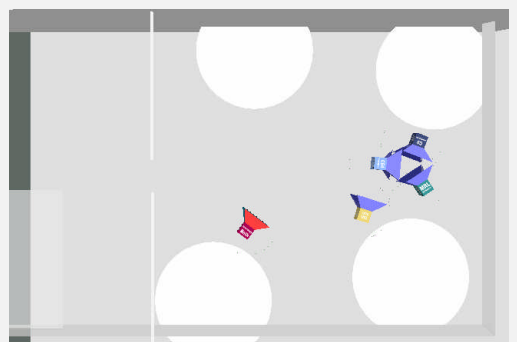
Time	15:33:56	
		

Scott starts moving away from the Bath MRACell and towards the group of three.

1	SH	You went for a coffee in the end	
2	GA	Yeah	

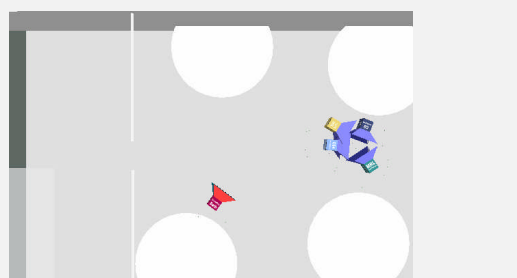
Maria enters the MRL MRACell and crosses into the MRL meeting space

Scott reaches the group of three from the South. Nobody moves. Sam is waving, acknowledging Scott's arrival.

Time	15:34:11	
		

3	GA	Felipe (inaudible)	
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As there is no space in the configuration, Scott moves around to the other side.

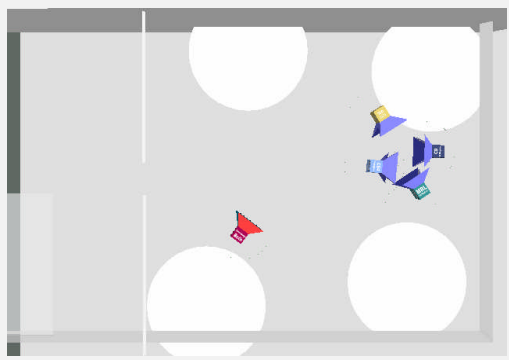
Time	15:34:19	
		

Sam is looking up and then starts pulling back while talking to Gemma.





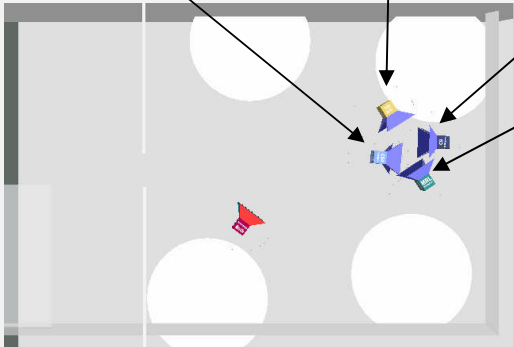
4	GA	(inaudible) interesting .. paper.	
5	SH	Alright, ok.	

6	GA	(inaudible) told me to.	
7	SH	...Calvin M., that is, or ..?	
8	GA	Felipe!	
9	SH	Felipe, oh (inaudible) yeah. Sorry, (inaudible).	

Maria is passing through the MRL MRACell coming from the meeting table. She stops briefly at the screen looking at it and then leaves through the main door. Sam's movement of the C9 MRACell frees up space but also allows him to face in the direction Scott is approaching from.

Time	15:34:30
	

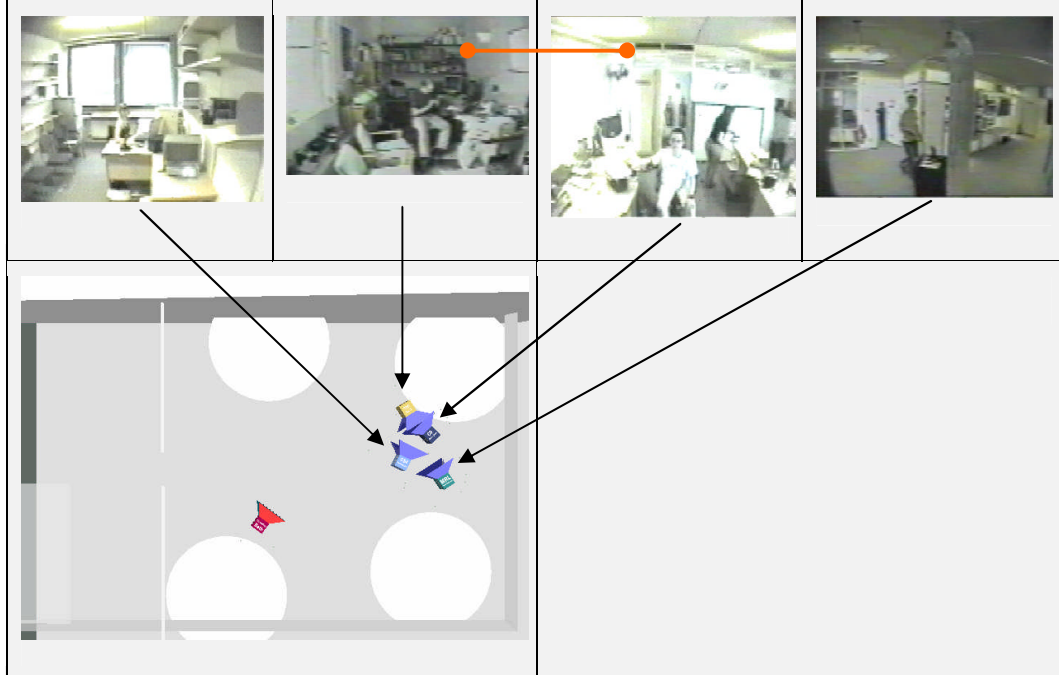
Scott move the 127C MRACell slightly closer to the C9 MRACell, but they are still not directly facing each other.

Time		15:34:44		
Room	C54	127C	C9	MRL
People	KB	SA	SH, GA	
				
				

10	SH	Hello, Scott.	GA can be seen taking the C9 phone to her
11	SA	Hello.	
12	SH	How are you?	

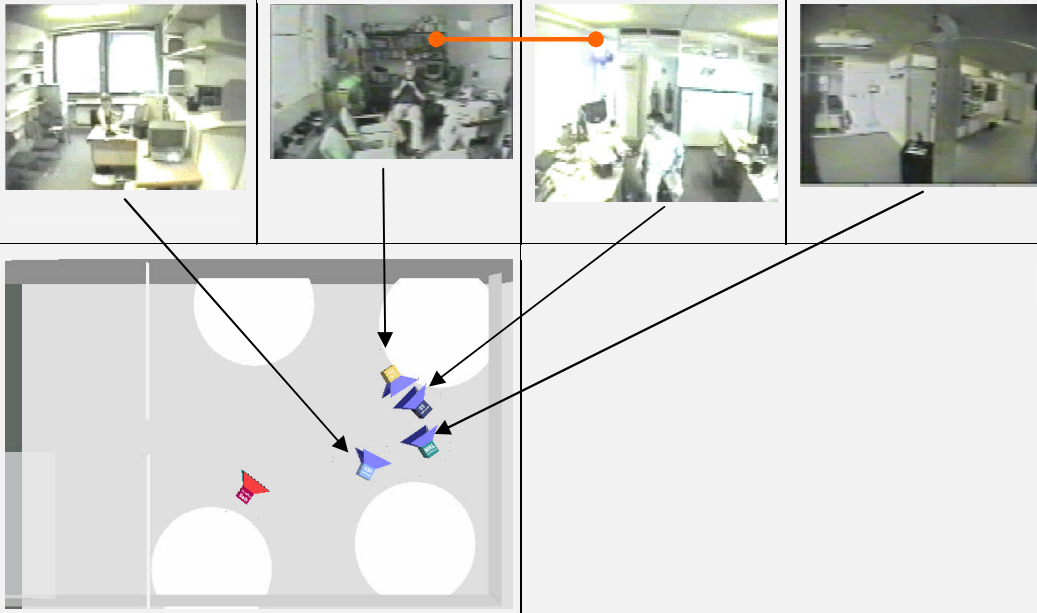
13 14	SA	Alright, I saw Peter earlier ... but unfortunately he was, aeh trying to invade a meeting.	desk in the background
----------	----	--	------------------------

C9 and 127C are moved closer together to face each other. Kate looks on from C54 and rotates her MRACell round. Gemma starts making a call in the C9 MRACell. Richard enters the MRL MRACell and glances at the screen briefly. He is followed by Maria who leaves again immediately after.

Time	15:34:54			
Room	C54	127C	C9	MRL
People	KB	SA	SH, GA	RS, MC
				

15	SH	.... Sorry?	
16	SA	Peter came charging through earlier (inaudible)	
17	SH	Ah, ok, ok. Did he do the same stalking .. movement again?	
18	SA	Sorry?	
19	SH	Did he stalk you again?	

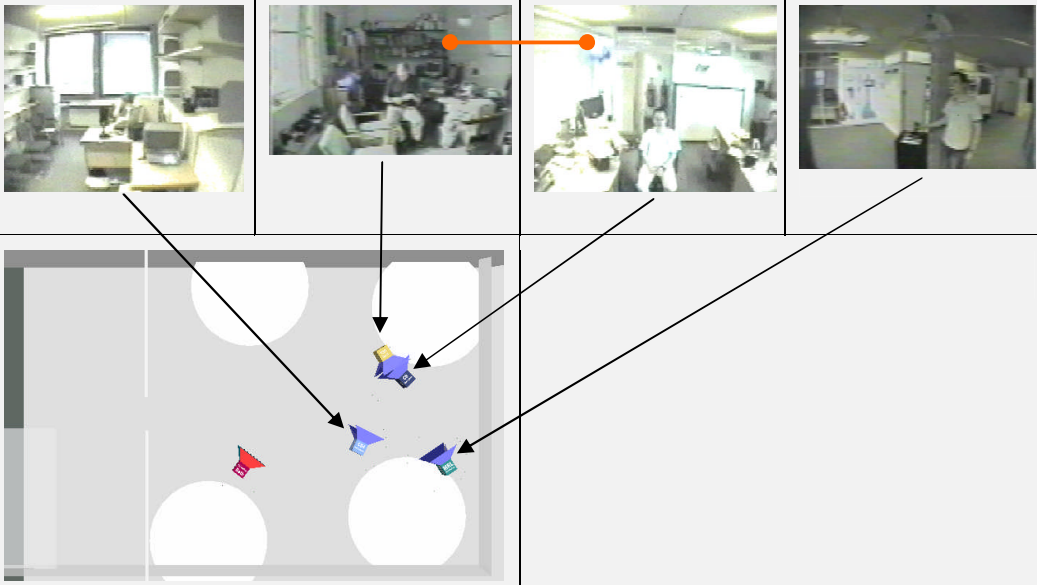
Sam pulls back C9 slightly because of some audio feedback. The C54 MRACell is still in audio range. Kate gets hold of the JS and pulls her MRACell back so it is out of range.

Time	15:35:07			
Room	C54	127C	C9	MRL
People	KB	SA	SH, GA	
				

20	SA	Yeah, basically (laughing).	<p>Moved to back of his office</p> <p>Moved forward again</p>
21	SH	(laughing) [ terrible.	
22	SA	[ People wanted to see as I appeared but I had it half	
23		closed and aeh .. talking to students.	
24	SH	Yeah, I saw him do that. I don't know why he doe .. aeh ..	
25		he, I don't think he knew what the semi-private thing was.	
26		I .. I said that today.	
27	SA	[Yeah	
28	SH	[Aemh	
29	SH	So he now knows that the yellow thing, when it's yellow it	
30		does mean .. you are in .. but not available. .... It, aeh	
31		the Bartlett machine has gone down, they have got a	
32		power .. aeh shut down.	
33	SA	(laughing) Probably too hot.	
34	SH	Sorry.	
35	SA	It's probably too hot. There is a problem with trying to run	
36		these experiments in the summer is that all these univer-	
37		sities, their air conditioning	
38	SH	Aeh.	
39	SA	All the machines shut down.	
40	SH	Yeah, there is just not enough power.	
41	SA	Yes.	
42	SA	Yes.	
43	SH	... Yeah.	
44	SA	... right, I should review some papers.	
45	SH	Ok (inaudible) what conference for?	
46	SA	Aaeehm .. Presence.	
47	SH	Ah .. Presence, ok.	
48	SA	[ Yeah.	
49	SH	[ Yeah.	
50	SH	That's good. Are they .. do you know (inaudible) anything	
51		interesting.	

52	SA	Aehm ... yeah, it looks good. Yeah, some of them look	
53		ok.	
54	SH	Ok.	
55	SA	Yeah.	
56	SH	We got the aemh ... the second Augurscope into the ..	
57		Special Issue .. on Virtual Heritage.	
58	SA	Oh yes, .. that's good.	
59	SH	Yeah.	
60	SA	That's good.	
62	SH	Yeah, I am very happy about that, the reviews were very	
63		bizarre though .. aeh	
64	SA	(inaudible) Presence?	
65	SH	Yeah ... I mean they ... it's hard to tell, I mean one of	
66		them, they, they hardly say anything, that's the problem;	
67		they are extremely short. .. Aehm, one of them just says	
68		yes, yes, yes, yes, yes ... and	
69	SA	Is this for the Journal?	
70	SH	Yeah for the journal, yeah.	
72	SA	Alright, I mean, they've been trying to raise the quality of	
73		the reviews so .. (inaudible) all mine are pages and	
74		pages long.	

Richard approaches the JS in the MRL MRACell and relocates away from the C9 and 127C MRACells, out of reach of their audio. Sam moves in a bit closer to 127C.

Time	15:37:08			
Room	C54	127C	C9	MRL
People	KB	SA	SH, GA	RS
				

75	SH	Sorry?	
76	SA	All my reviews are pages and pages long.	
77	SH	Alright.(inaudible) I don't get that. We got literally, we got one page reviews .. at most, I think.	

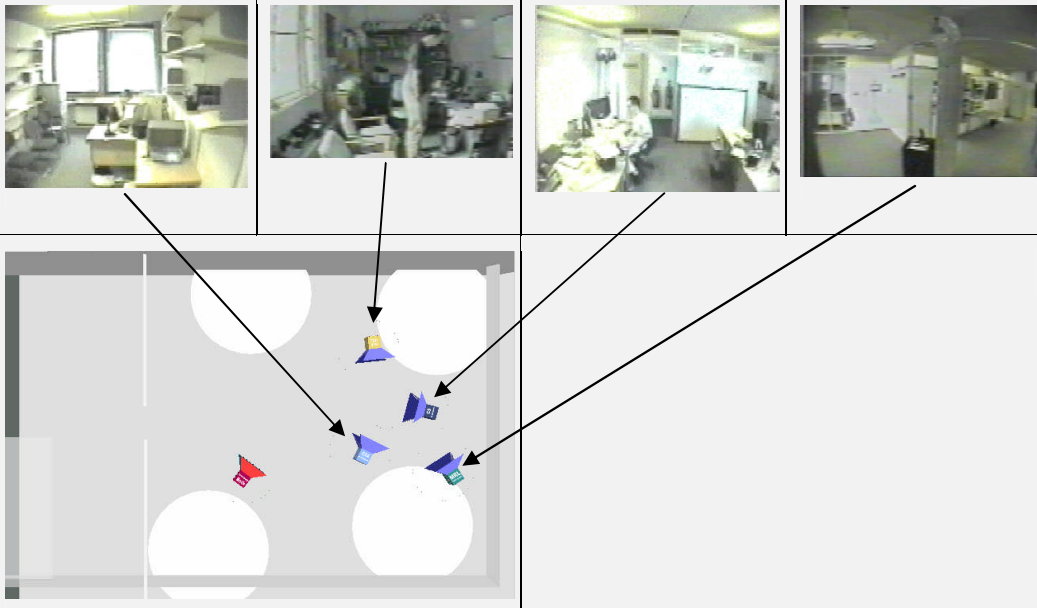
Maria enters through the main door in the MRL, crosses the MRACells and walks into the meeting space, to have a meeting with Richard who is already waiting there.



78	SA	Yes
79	SH	Yeah ... So they want us to shorten the paper, but we are
80		not really sure where and how, because they didn't really
81		.. say that much about that part (laughing) .. they just
82		said it was too long (laughing).
83	SA	... Well (inaudible) do that for?
84	SH	Yeah
85	SA	When have you got to do it for?
86	SH	Oh, end of October.
87	SA	Ah, ok.
88	SH	Yeah (inaudible).
89	SA	I have got a couple more papers coming out .. in Pres-
90		ence, later this year.
91	SH	Sorry, say it again?
92	SA	I have got a couple more papers coming out in Presence,
93		later this year.
94	SH	Oh, good. What are they about?
95	SA	Aehm, interaction with the CAVE.
96	SH	Ah, ok, ok, ah. ... And, and in what way. What do they
97		(inaudible) something?
98	SA	Aemh (inaudible) 3D interaction, if there is somebody
99		else in the CAVE with you or if they are not head-tracked
100	SH	Oh, ok, yeah.
101	SA	(inaudible) small variations on aeh (inaudible).
102	SH	Yeah, and what was the experience, what did the people
103		experience?
104	SA	Sorry, what.
105	SH	What, what did people look at? What was .. was their vir-
106		tual experience.
107	SA	Oh it's a very aeh interaction focussed (inaudible) com-
108		pletion times, error rates, there are selecting objects and
109		pointing and things like that.
110	SH	Ok, ok [ yeah.
110	SA	[ Fairly low level stuff.
112	SH	Yeah, was it using the aeh EEG stuff or whatever you call
113		it, the brainwave stuff.
114	SA	You virtually just have ... have (inaudible) people point-
115		ing at stuff (laughing).
116	SH	Ok, ok [ mmmhh
117	SA	[ So .. very gesture based.
118	SH	Yeah.
119	SH	.... Alright then.
120	SA	[ Yeah.
121	SH	I'll aeh, probably (inaudible) hopefully (inaudible) ..I won't
122		start the Bartlett this afternoon, because (inaudible) ap-
123		parently it only comes up, right .. roughly right now and I
124		am wondering whether they will turn the machine up as
125		a, as a aeh .. matter of urgency, so it probably stays off
126		for a while.
127	SA	Right, you know you are going to do some more re-
128		recording .. later in summer, next week maybe?
129	SH	I probably won't do much next week. It depends on
130		whether I can find a day where you are all in?
131	SA	Right
132	SH	And I am also, also going on holiday from aeh, aeh ..
133		Thursday.
134	SA	Ok.
135	SH	Sarah will be away the week after and the week after that
136		and Kate is away as well, so ... I probably try to do more
137		in September.

138	SA	Right, you best let me know when (inaudible) away the	
139		back end of September	
140	SH	You are gonna be away in September?	
141	SA	Aeh, quite a lot, yeah.	
142	SH	Yeah, ok.	
143	SA	Aehm, so I go on holiday on about the 23rd of August	
144	SH	(inaudible) of August?	
145	SA	23 <sup>rd</sup> !	
146	SH	Oh, yeah, ok.	
147	SA	And I am away for two weeks and back in for a couple of	
148		days and away for another week.	
149	SH	I am coming back the 23rd so (inaudible) looks like there	
150		is going to be long periods where nobody is in (laughing)	
151	SA	Yeah.	
152	SH	That's alright, I mean ... I think probably .. the later half in	
153		September is more likely now that it's going to be useful [	
154		for me	
155	SA	[ Yeah.	
156	SH	(inaudible)	
157	SA	Yeah, we are back in term time so more people are	
158		around.	
159	SH	Yeah .. that's true.	
160	SA	.... Ok, [ (inaudible)	
161	SH	[ Ok, have fun reviewing ... Yeah, good plan.	

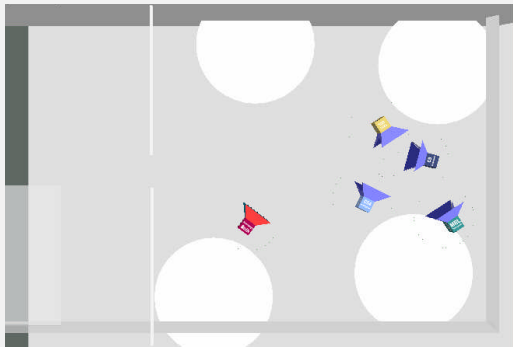
The two MRACells are separated by both, Sam and Scott, pulling back. Gemma is still on the phone in C9.

Time	15:41:14			
Room	C54	127C	C9	MRL
People	KB	SA	SH, GA	
				

Scott starts making his way out his office but then returns. C9 and 127C are not in audio range anymore.

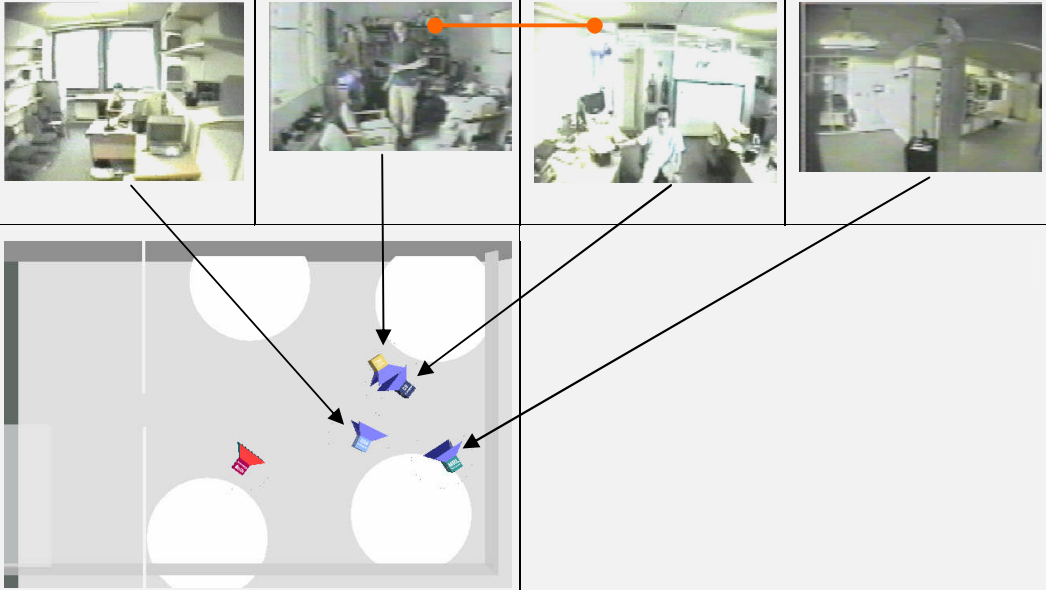
162	SA	Oh, .. Sam ...	Out of audio range
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He gets hold of the JS and starts navigating the 127C MRACell back to C9. He then reaches the audio range of C9.

Time	15:41:20		
			

163	SA	Sam ?	
164	SH	Yeah.	
165	SA	Did you sort out the RADMIN?	
166	SH	Aeh, it worked this morning.	
167	SA	Yeah ..	
168	SH	I just [ have no idea why it sometimes works and some-	
169		times doesn't	
170	SA	[ Very strange, it worked for me as well	





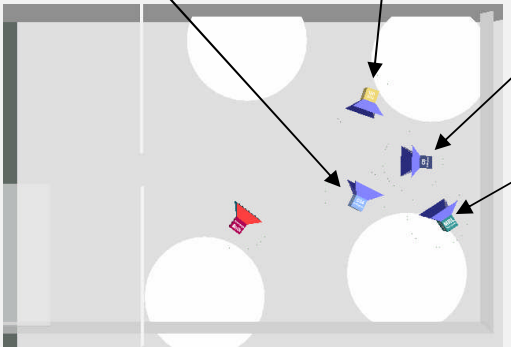
By this time Sam has moved his MRACell even closer to the 127C MRACell.

Time	15:41:35			
Room	C54	127C	C9	MRL
People	KB	SA	SH	
				

171	SH	You are not .. you are not trying to (inaudible) log in from	
172		different machines, are you?	

173	SH	No, no just from that single one ..I mean, I mean the	
174		good new is the automation .. the automation thing works	
175		now.	
176	SA	Yeah.	
177	SH	So, this morning I didn't have to do anything, it just	
178		started up automatically.	
179	SA	Ok. Aeh, I mean RADMIN just works (inaudible) I am	
180		logged in, so I don't know what's wrong with it at all	
181	SH	Yeah, it's weird.	
182	SA	Yeah.	
183	SH	Hmm.	
184	SA	Ok.	
185	SH	Ok, cheers, thank you.	

Sam and Scott pull back out of other MRACell’s audio ranges and rotate round a little. Scott leaves his office, coffee cup in hand. Sam gets back to his desk. Gemma is still on the phone.

Time		15:42:07			
Room	C54	127C	C9	MRL	
People	KB		SH, GA		
					
					

### 11.2.3.e Vignette 6 – Collaborative Exploration

Date	Start time	Duration
30/07/2004	16:00:41	8 min 12 sec

#### Context

This vignette shows the collaborative exploration of the MRA by Fred (FM) and Sarah (SD). Their actions lead to two encounters at two of the MRACells and two attempted encounters at the other two MRACells, where either nobody is available for interaction or those available are not directly approached.

Fred and Sarah open their MRACell, move over to the C9 MRACell where they have a conversation with Gemma (GA). They then navigate to the MRL MRACell where two people are just leaving. After moving to the C54 MRACell they have a conversation with Kate (KB) their. They then approach the 127C MRACell, where nobody appears in camera view. Fred Sarah then move back to nearly exactly their starting position and close their MRACell.




#### Vignette

The 4.9 MRACell is closed and the projector is turned off. Fred and Sarah are working together in that office. The EngD, C9 and C54 MRACells are arranged in an open rectangle. The MRL MRACell is sitting back facing the group of three and a meeting is taking place there. The Bartlett MRACell is off, because of a local power shut down. Sam (SH) is just returning to C9, where Gemma is working at her desk. Kate and Scott (SA) are working at their desks in C54 and 127C respectively.


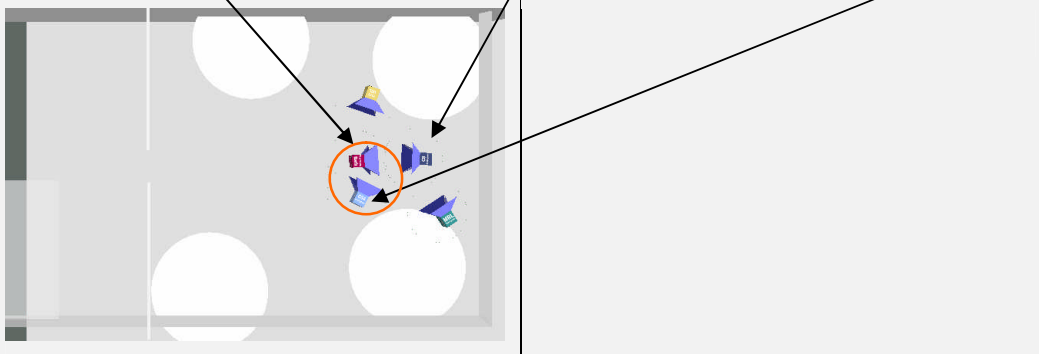
Time	16:00:41		
Room	4.9	C9	C54
People	FM, SD	SH, GA	KB

Fred and Sarah are getting up. Sarah turns on the projector and while it is powering up, hands the joystick to Fred. She is showing him some of the joystick buttons. At this point Sam gets up from his desk and leaves C9.

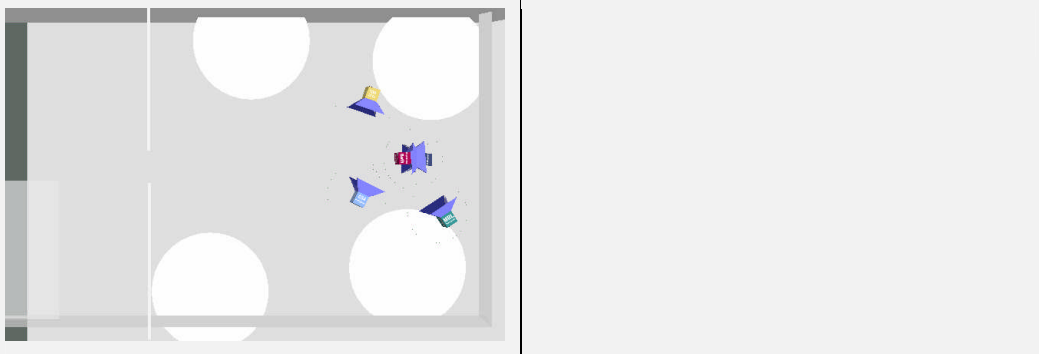
Back in 4.9, it appears that Fred has some difficulty and rotates for a bit with the MRACell still set to red (private). He then sets it to yellow, back to red and finally sets it to blue (open). At this point Sam enters the MRL through the main door, followed by Cliff. Sam walks past the screen and into the MRL library space. Fred starts re-configuring the MRA by moving the 4.9 MRACell towards the group of three MRACells. Sarah is looking on.

Time	16:02:46		
Room	4.9	C9	C54
People	FM, SD	GA	KB
			
Error! Objects cannot be created from editing field codes.			

Sam walks past through the MRL MRACell from the MRL library into Glenda's office, glancing at the screen. He can be heard talking to Glenda in the background. Sarah can be heard pointing out various other MRACells to Fred. When they pass the C54 MRACell, Kate looks up. The MASSIVE3 recording shows that the audio streaming from 4.9 (discussion where to go next) was audible in the C54 MRACell. The interaction that follows at the C9 MRACell takes place within full view of C54.

Time	16:03:20		
Room	4.9	C9	C54
People	FM, SD	GA	KB
			
			

Fred and Sarah reach the C9 MRACell.

			
--	--	--	--

1	SD	Hello? ...	
2	SD	(inaudible) be near by, because I can see his [ door open	
3	FM	[ (inaudible)	
4	SD	Or may be Xenia is in there .... or Gemma.	
5	SD	Hello? .... Ah, its Gemma.	

Gemma is getting up and moves forward towards the screen near the JS.

Time	16:03:33		
Room	4.9	C9	C54
People	FM, SD	GA	KB
			


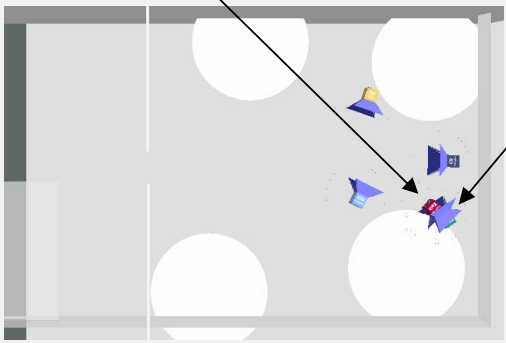
6	GA	Hello	FM still re-positioning GA pulls back Waving Waving
7	SD	Hi Gemma	
8	GA	Hello. ... Aeh, [(inaudible) .. I can't see anything	
9	SD	[Uh you have gone full screen ....Fred is here, as well	
10	FM	Hello	
11	GA	Hello (laughing)	
12	GA	Aeh .. He's not here at the moment	
13	SD	Oh, Ok .. We (inaudible) We saw the door was open. So	
14		[ we thought he might be around.	
15	GA	[ Oh, Ok (laughing)	
16	FM	(laughing)	
17	GA	Yeah, I think he is kind of .. trying to organise the Ubi-	
18		Comp stuff, so he is in and out the whole time.	
19	SD	All right, ok, all right .. we'll come back later.	
20	GA	Ok (laughing). See you.	
21	SD	See you. Have a good weekend. Bye.	
22	GA	Bye.	

Fred pulls back the 4.9 MRACell with Sarah looking on, while Gemma gets back to her desk out of sight of the camera.

23	SD	Say hello to Kate? ... (Inaudible)	
----	----	------------------------------------	--

Fred moves the 4.9 MRACell over to the MRL MRACell. When they arrive, two people are just leaving through the main door.



Time			
Room	4.9	MRL	
People	FM, SD	2 People	
			
			

24	SD	(Inaudible) the MRL. It's open, too.. it's not Sam, is it?	People leaving Door closing
25		(inaudible) say hello	
26	FM	Who's that?	
27	SD	.. don't know	
28		(inaudible) walking through	

Glenda's voice can be heard from her office, which is directly in camera view but cannot be looked into. Sarah and Fred are looking into the MRL, moving about a little.

29	SD	It's quite funny, because they've to got aehm ... it's not	
30		very good because they have got a meeting. They'll be	
31		able to hear us (laughing) on the other side ... (inaudible)	
32		yeah move away.	


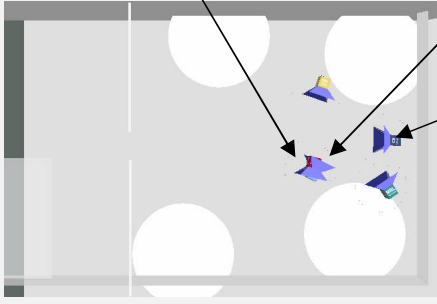
Fred pulls back with the 4.9 MRACell and turns around, heading for the C54 MRACell. On their way they face the 127C MRACell in the distance.

33	SD	Say hello to Scott, because (inaudible)	
----	----	---	--

Fred keeps going, turning around towards the C54 MRACell.

34	FM	(inaudible) Kate?	
35	SD	Yeah ...	


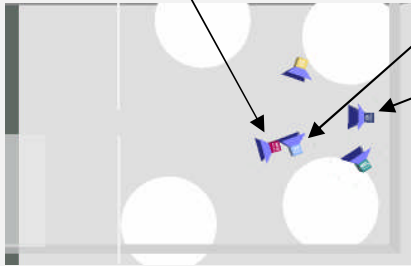
The 4.9 and C54 MRA Cells are now facing each other

Time	16:05:16		
Room	4.9	C54	C9
People	FM, SD	KB	GA
			
			


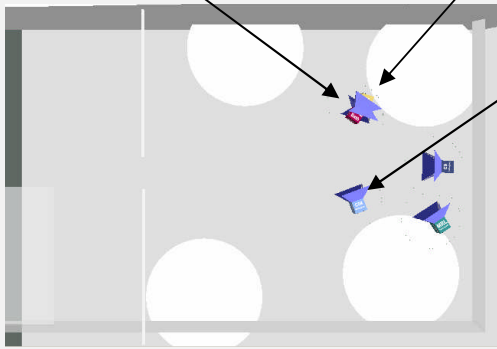
36	SD	Hello?	Looking up, facing screen
37	KB	Hello	
38	SD	Hi, how are you	Repositioning Gets up, Moves close to screen
39	SD	I have got a visitor, do you recognise him?	
40	FM	(laughing) ... Hello	
41	KB	Hang on ...	Leaning over into middle of frame
42	FM	Ah there you are. In the other end (inaudible) almost hidden.	
43	SD	Oh, we or Mike? .. Uh	
44	KB	No, Mike	Re-positioning
45	KB	(inaudible) say. Yes, he is not in good shot	
46	FM		
47	FM		
48	KB	Hello	
49	FM	Hello	
50	KB	How are you doing?	
51	FM	Not too bad ... Ahhhh (sigh).	
52	SD	If you ... if you move a tiny bit back you'll be able to see more ... you'll be able to see that you are on there.	
53	SD		
54	FM	Having some Joystick [ issues	
55	SD	[ Oh, yes (inaudible)	
56	KB	Ah, that's better (laughing)	
57	FM	Excellent.	
58	SD	So, it's warm in Nottingham, is it nice and sunny for the weekend?	
59	KB	Yeah, it .. it was cloudy earlier, but it seems to be getting nice and warm	
60	FM	Sure	
61	KB	(inaudible) .. I am looking forward to not doing anything on the weekend.	
62	KB		

67	FM	Yehey	
68	SD	(laughing), yeah, so are we (laughing).	
69	FM	Fantastic .. Cool .. Are you around next week, at all?	
70			
71	KB	Yeah, yeah, I am here next week and then I am going on holiday.	
72			
73	FM	Alright .. cool, I may well pop in sort of early in the week. Aeh ..	
74			
75	KB	Aeh ..	
76	FM	I need to come and say high to Sam before he goes away.	
77			
78	KB	Yeah, yeah, should be good. I saw you submitted a paper to .. the workshop at UbiComp	
79			
80	FM	Ah, yes I did yeah, Peter .. Peter wrote to me and said 'Could you .. write one?' So I wrote one in about half an hour (laughing) [ so probably not very good I am afraid.	
81			
82			
83			
84	KB	[ Yeah we needed some more submissions.	
85	FM	(laughing) How many submission have you got? Do you know?	
86			
87	KB	Aehm ... 6 without our one.	
88	FM	Right. So	
89	KB	So, there will be about 10 papers on the day, which [ will be fine.	
90			
91	FM	[ Oh this is cool.	
92	KB	But, you know.	
93	FM	Excellent, ah that's pretty good actually.	
94		Karl was getting very worried whether his would get in.	
95			
96	FM	Yeah	
97	KB	What?	
98	SD	Karl D.	
99	KB	Oh .. get in (laughing)	
100	FM	Hurray (laughing)	
101	SD	[ He'll be very pleased.	
102	KB	[ If he wants to do another paper, you know, it's not too late.	Gesturing
103			
104	FM	(laughing)	
105	SD	He ... He's very excited about going to that workshop .. so (laughing)	
106			
107	KB	Aehm, .. good good [ (inaudible)	
108	FM	[ Excellent .. now that's why I need to speak to Sam actually, because we need to work out which room to have which workshops in, [ aeh ..	
109			
110			
111	KB	[ Yeah	
112	FM	depending on how many come to each one .. so ...	
113		.Cool ..	
114	KB	OK	Moving back from screen
115	SD	(inaudible) have a good weekend	Waving
116	FM	Yeah, have a good weekend Kate.	
117	KB	Thanks, you too.	
118	FM	Bye	Waving
119	SD	Bye	
120	KB	Bye, bye	

Kate gets back to her desk and sits down. Scott can be seen getting up from his chair before leaving 127C. Fred pulls back with the 4.9 MRACell.


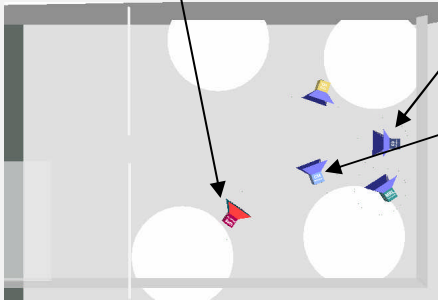
Time	16:07:41		
Room	4.9	C54	127C
People	FM, SD	KB	SA
			
			

Fred pulls back and turns the MRACell around and then heads towards the 127C MRACell. Sam is leaving Glenda's office, glancing at the screen twice, before leaving the MRL via the main door. Fred has re-positioned the 4.9 MRACell so it now faces the 127C MRACell.

Time	16:08:13		
Room	4.9	127C	C54
People	MF, SD		KB
			
			

121	SD	Hello?	
122	FM	I don't think he is in	
123	SD	No, not (inaudible) .. (laughing)	
124		It's weird (inaudible) talking to someone and they are	
125		not there (laughing).	
126	FM	A bit nosy.	
127	SD	(laughing) could be round the corner.	

Fred pulls back with the 4.9 MRACell, still facing the empty 127C and in direct view of the C9 MRACell. Fred and Sarah are talking about the various privacy settings and what the different colours mean. Sam enters the C9 MRACell and sits down at his desk. Gemma mentions that Fred and Sarah were wandering about and talking to Boriana before she asks about the different privacy settings. For both of the above conversations, the audio quality on tape and MASSIVE3 recording is too poor to be transcribed. Fred closes the 4.9 MRACell.

Time	16:08:53		
Room	4.9	C9	C54
People	FM, SD	SH, GA	KB
			
			

Fred and Sarah are leaving the 4.9 MRACell. The door can heard to close behind them.

### *11.2.3.f Vignette 7 – Finding someone in MRA*


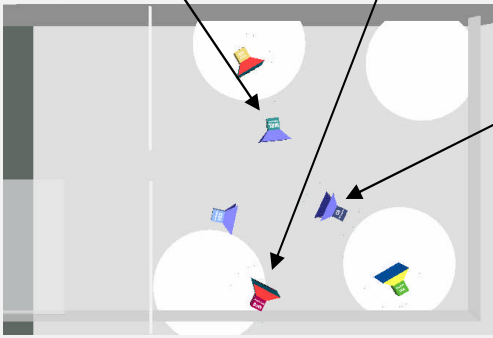
Date	Start time	Duration
29/10/2004	15:12:58	12 min 34 sec

#### **Context**

This vignette describes four interactions taking place within MRA, interwoven with other events. All four are the result of someone attempting to find another inhabitant of MRA. Firstly, Eric (ES) enters the C9 MRACell physically and attempts to find one of its inhabitants, most possibly Sam. Gemma (GA) tells them that the person is elsewhere in the building. Secondly, Sarah (SD) reconfigures MRA by placing her own MRACell close to the C9MRACell, where she is trying to get in contact with Sam (SH). Gemma tells her that Sam is elsewhere in the building. The conversation between Sarah and Gemma that follows covers the possible weekend use of MRA. Thirdly, Sarah reconfigures MRA again by moving her own MRACell closer to the MRL MRACell. Another attempt to locate Sam at first fails, but succeeds, when Sam physically passes through the MRL MRACell, by coincidence. A conversation between Sam and Sarah follows, covering the re-location of the MRACell and privacy issues. Finally, this conversation is briefly interrupted by a chance encounter at the MRL MRACell, when Maria and Sarah have a short chat about an upcoming paper submission.

#### **Vignette**

The C9, C54 and MRL MRACells are arranged in an open triangle and are set to blue (open state). Nobody appears in camera view in C9 or in the MRL. The 1.2a MRACell is set to red (private state) facing the other three. Sarah is sitting at her desk. The other two MRACells are located further back and play no part in this vignette.

Time	15:12:53		
Room	MRL	1.2a	C9
People		SD	
			
			


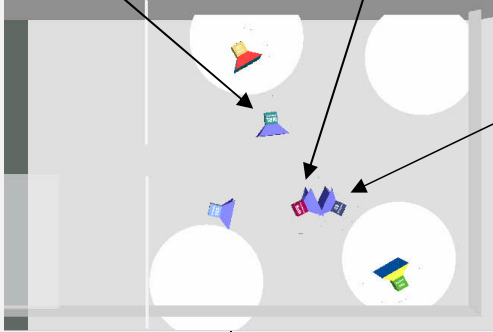
Sarah gets up from her chair, moves towards the keyboard and opens her MRACell. Eric opens the door to C9 and asks Gemma about the whereabouts of somebody else (most likely Sam).

Time	15:12:58		
Room	MRL	1.2a	C9
People		SD	ES, GA
			
			



1	ES	Morning	
2	GA	(Inaudible) ... he is somewhere [ around (laughing)	
3	ES	[Ah	

The person pulls their head back and closes the door. SARA H then starts re-configuring the MRA, positioning the 1.2a MRACell close to the C9 MRACell.

Time	15:13:31		
Room	MRL	1.2a	C9
People		SD	
			
			

Sarah calls out into the C9 MRACell


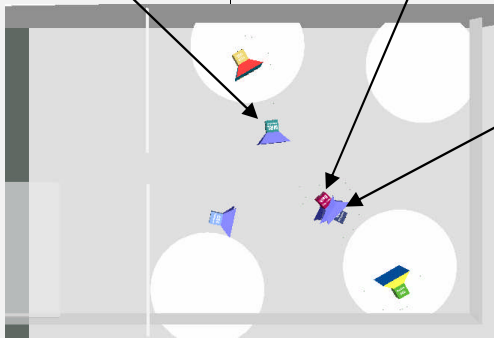
4	SD	Hello?	Chair movement can be heard in C9
5	GA	Hello	

Gemma gets up from her chair. This triggers the automatic lights to come on in C9.

6	SD	Hi there, is eah [ Sam around, Gemma?	
7	GA	[ Hi	

Gemma moves towards the JS, gets hold of it and faces the screen. SARA H is still navigating to find a suitable position.

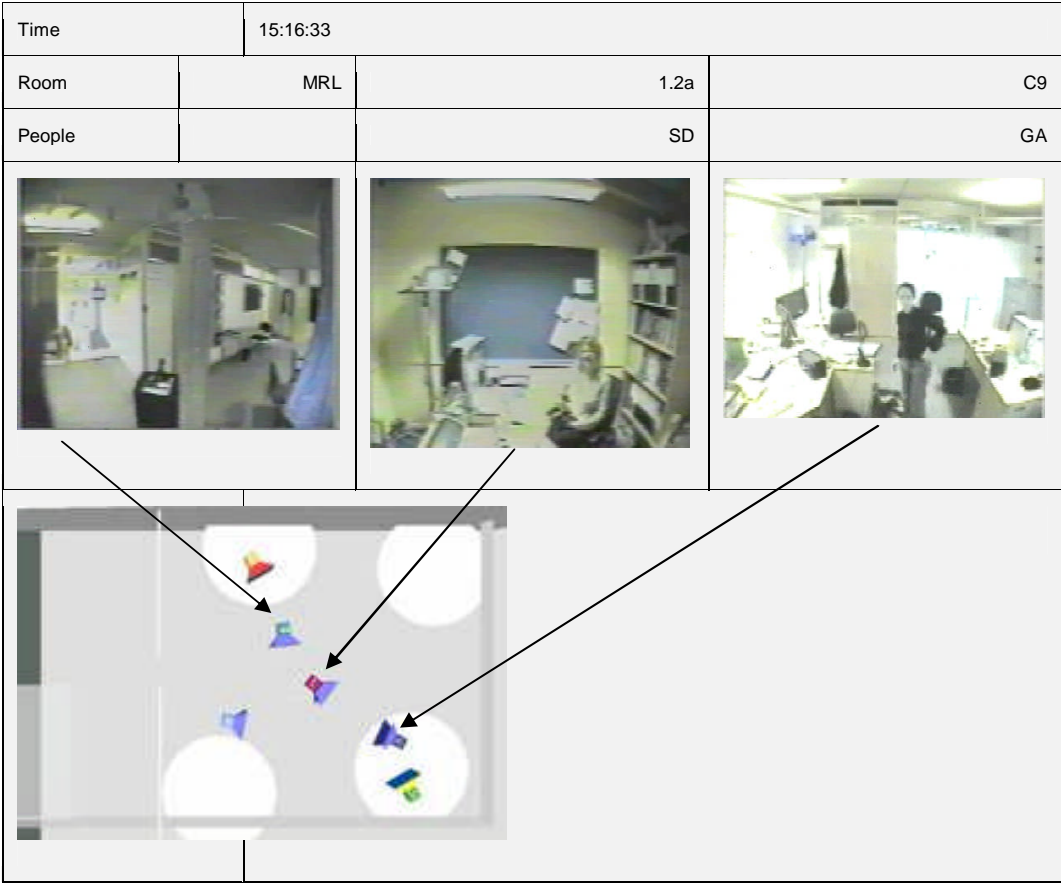


Time	15:13:43		
Room	MRL	1.2a	C9
People		SD	GA
			
			

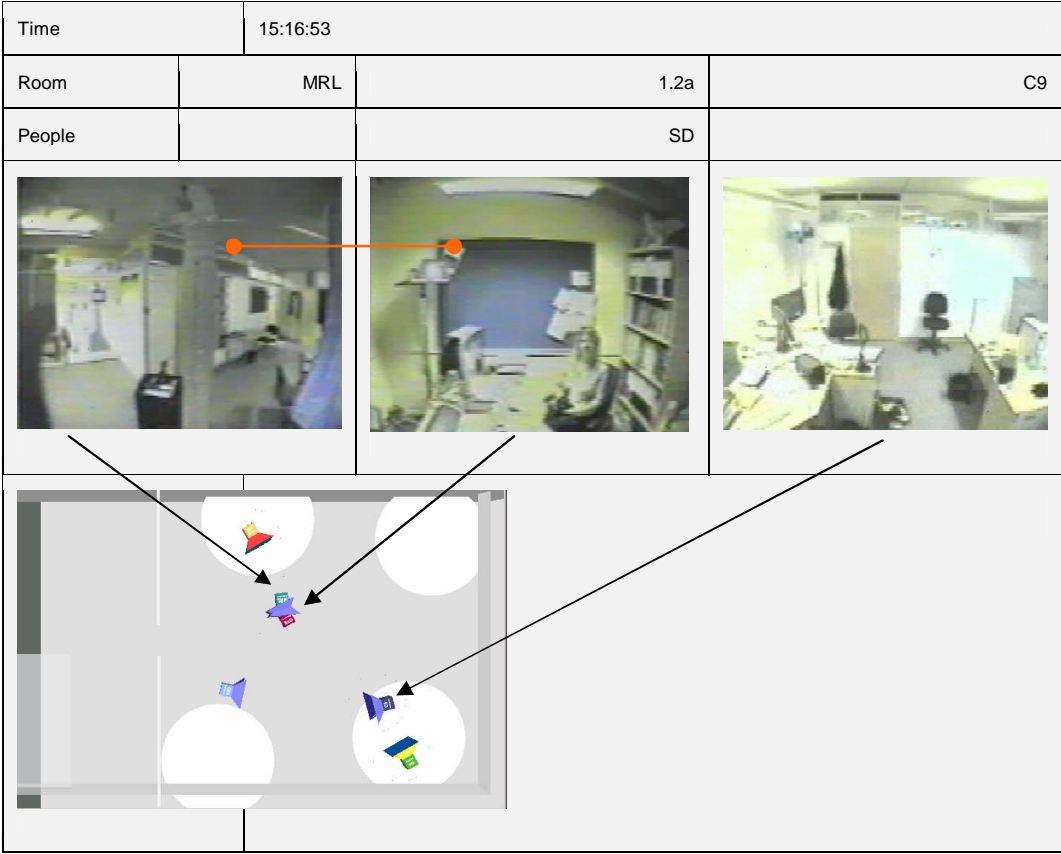
8	GA	Ah, eeah.
9	GA	[ (laughing)
10	SD	[ You are moving the boundary, it's a bit odd.
11	GA	Hmmh, he ... he ... he is around, but he is not in the office.
12	SD	Alright, ok, how are you, you are alright?
13	GA	Hmmh, ok, yeah .. writing! [ (laughing)
14	SD	[ Writing again, yeah .. , I am getting writing again as well, it's been really hectic.
16	GA	Oh, ok, (laughing) Ah, I think, Ah, Sam is going to change the boundary downstairs, he is going to move it ... to inside the lab actually it [
17		may be he ...
19	SD	[ Alright, ok.
20	GA	he's taking care of this may be now or ... he will do it very soon ... he
21		was taking like pic .. hmm .. questionnaires with people downstairs and
22		[ he was yeah ...
23	SD	[ Ah, ok.
24	GA	getting ...
25	SD	Well, I'll go to the boundary downstairs then and see if he is there. If
26		not, can you tell him I called by?
27	GA	Ok, are you going to be around, or?
28	SD	Aeh .. Yeah, Aeh .. I am around for the next sort of quarter of an hour,
29		twenty minutes, if he comes back.
30	GA	Ok and then are you off for the weekend?
31	SD	Oh, no, no, I am still here I'll just probably have my boundary closed
32		because I'll have some students in.
33	GA	Aah, ... Can I ask you something?
34	SD	Yeah.
35	GA	Yeah. Do you go to the office at the weekend at all?
36	SD	To my office in Bath?

37	GA	... Yes, yes
38	SD	No, I used to all the time at my office in Nottingham. I don't in Bath be-
39		cause I am commuting for two hours.
40	GA	Yeah, [ ok
41	SD	[ I do some work from home, if am going to do work at the [weekend
42	GA	[Yeah, we had because we had this discussion with Sam .. aeh ..
43		whether .. people would use the boundary in the weekend, if they are
44		in their offices [ and
45	SD	[ Ahhh
46	GA	He said that he never thought about it because heeee assumes that
47		the boundary .. aeh .. likepeople do not go to their offices in the week-
48		end (laughing).
49	SD	I think people do aeh ..
50	GA	Yeah
51	SD	It would be a different case, if I lived near by
52	GA	Yeah
53	SD	At Nottingham, I would often pop in on Saturday or Sunday, or do
54		some odds and ends, especially Sunday
54	GA	Yeah.
55	SD	to get things done. But I wouldn't do that here because I have to travel
56		so far [ (inaudible)
57	GA	[Yeah
58	SD	[ (inaudible)
59	GA	[Yeah
60	SD	do the commute
61	GA	Yeah. Because we were saying that may be .. the dynamics are
63		slightly different on .. Saturday or on Sunday because it's quite quiet ..
64		[so
65	SD	[That's it.
66	GA	You, you always try to find someone to have a chat for a little while
67		and then go back to your work.
68	SD	That's it.
69	GA	[ Aeh
70	SD	[ Yes, I think it would be, I think you are right.
71	GA	Yeah, but he says that the system is completely shut down during the
72		weekend, it .. it doesn't do anything, I mean even if you log on, you
73		cannot do it.
74	SD	Alright, I didn't realise that.
75	GA	Yeah, it's just (inaudible) during weekdays.
76	SD	Yeah, cause I have always assumed, like when I went to my office in
77		Nottingham I never used to (inaudible) it on on the weekend, because I
78		just assumed, no one else was around.
79	GA	Yeah (laughing). Yeah, Ok?
80	SD	Right, have a good weekend
81	GA	Yeah, you too, [ bye
82	SD	[ See you later

Gemma walks back to desk, then turns back to the JS, gets hold of it and pulls the C9 MRACell back. Sarah, sitting in her chair, also pulls backwards with the 1.2a MRACell.


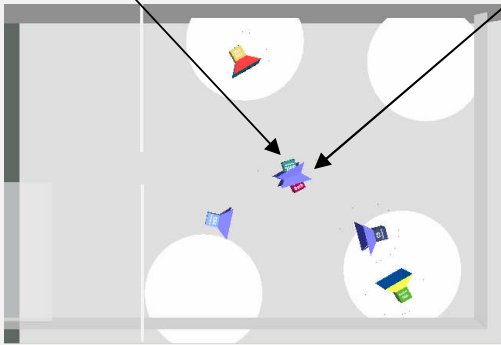


Both are then re-orienting their MRACells. The C9 MRACell is now facing the C54 MRACell in the distance, too far away for an audio connection. Sarah then moves the 1.2a MRACell over to the MRL MRACell. Nobody is in camera view there when she arrives.




83	SD	Sam?	
84	SD	Sam?	
85	SD	Sam?	

As nobody is in view and nobody is replying, Sarah starts pulling backwards, still facing the MRL MRACell. At that time Sam enters from the main MRL lab, walks towards the JS stand, takes hold of the JS and follows the 1.2a MRACell with the MRL MRACell until she catches up with Sarah.

Time	15:17:13		
Room	MRL	1.2a	
People	SH	SD	
			
			


86	SH	Hello Sarah.	
87	SD	Oh, did you hear me?	
88	SH	No.	
89	SD	Oh, I was calling you in the lab.	
90	SH	Oh, really?	
91	SD	Yeah I was calling you across the boundary: Sam? ..	
92		like this and like I did it three times and then I thought I	
93		drive Hazel and Dave mad.	
94	SH	(Laughing)	
95	SD	Actually Hazel is away isn't she?	
96	SH	Yeah, no she isn't hear, she is on holiday this week	
97	SD	Yeah, could see her office was dark	
98	SH	[emh	
99	SD	[emh	
100	SH	No, I was just passing by back on the way up ... basi-	
101		cally	
102	SD	Alright, I thought you had heard me because I was	
103		just pulling away cause I just I thought I can not keep	

104		shouting	
105	SH	(laughing) No, I didn't hear that at all. Do you know that	Pointing at floor
106		I am going to move this installation here inside the lab	
107		next week?	
108	SD	Did I know you have got a what? Sorry you went (inaudible)	Waving hands
109			
110	SH	Aeh, I will .. I will move this installation in the lab .. in	Pointing at floor
112		the meeting space here inside the lab	Pointing over
113	SD	Into the lab space?	shoulder to lab
114	SH	Yeah	main lab
115	SD	Alright, excellent, [ ok	
116	SH	[ Yeah	
117	SD	That'll be interesting then	
118	SH	I think It's been out here enough ... aeh, long enough	Pointing at floor
119		to kind of (inaudible)	
120	SD	Your audio keeps cutting in the middle of your words.	Cutting move-
121		It's really odd.	ment
122	SH	May be, if I come closer, is that better?	Moves towards
123	SD	Yeah, that's better, Yeah.	screen

Time	15:18:27		
Room	MRL	1.2a	
People	SH	SD	
			


124	SH	Emh .. it's .. just that it's been here .. out here	
125		enough .. eah .. time for me to know what it's like	
126		and I think the use inside the lab will be much dif-	
127		ferent	
128	SD	Yeah. No, ok, well I will have a go with that then.	Leaning forward to
129		Yeah, sorry, I have been really rushed today. I am	adjust speaker
130		writing a ... I am finishing writing something and I	volume
131		have got a load of marking and everything and my	
132		student wouldn't come in my office cause the	
133		boundary was on.	

Gerald walks through the MRL foyer and leaves through main door, Marcus walks towards the JS stand and lingers in view of the camera looking at the screen but does not say anything during the entire time he is there.

Time	15:18:46		
Room	MRL	1.2a	
People	SH, MF, GC	SD	
			



134	SH	Alright	
135	SD	So .. It was really funny, some of them insisted on meeting outside	
136			
137	SH	Really?	
138	SD	cause they didn't want to be on the video.	
139	SH	That is quite amazing [ (inaudible)	
140	SD	[ I know	
141	SH	Yeah, .. how many of them?	
142	SD	Aeh, it was one .. one person who came to visit me and one of my dissertation students.	
143			
144	SH	And did you .. did you know whether they didn't want to be on the recording or ..	
145			
146	SD	They wouldn't even come into the room. They actually said to me 'do you mind if we meet outside the door'?	
147			
148			
149	SH	Right, ok [ (inaudible)	
150	SD	[ (inaudible) I had to meet one of them outside the door, talk about her study, sign her .. her thing, everything, she wouldn't come in the room. That's really odd, isn't it?	
151			
152			
153			
154	SH	Yeah, it is. And, did they eah did they do that because they saw the sign?	
155			

Marcus leaves towards the lab entrance. Maria enters from the main lab.

Time	15:19:25		
Room	MRL	1.2a	
People	SH, MF, MC	SD	
			

156	SD	Aeh, well I warned it was recording. Cause she	SH waving good
157		knocked on the door and I said 'oh by the way' ..	bye to MF
158		and she said ' oh I prefer not to come in'	


Maria has come closer to the screen appearing behind the pillar in camera view, while Marcus can be seen exiting the lab.

Time	15:19:34		
Room	MRL	1.2a	
People	SH, MC	SD	
			

159	SH	(laughing) Do you recognise who it is?	Turning towards
160	SD	Oh, it's Maria	MC
161	SH	Yes (laughing)	
162	SD	Hi Maria	
163	MC	Hello (laughing)	
164	SD	Hello, I have been telling Sam I've .. I have my	
165		boundary closed most of the mornings and I was	
166		desperately writing (laughing)	
167	MC	Good (laughing) I can see you desperately writing	
170		MC, SH: (laughing)	
171	SD	How are you?	
172	MC	I am fine, (inaudible)	
173	SH	Yeah	
174	MC	(inaudible) on Monday (inaudible) my	
175	SD	Sorry I missed what you .. I am not hearing you	
176		very well Maria	
177	SH	(inaudible) lost (inaudible) a bit closer	Turned towards
178	SD	S: Yeah, the audio eah is a bit disjointed.	MC, then pointing at screen

Maria steps forwards to come closer to the screen.





Time	15:20:16		
Room	MRL	1.2a	
People	SH, MC	SD	
			

179	MC	(inaudible) .. something in on Monday.	
180	SD	[ Yeah.	
181	MC	[ Otherwise we won't get it in.	
182	SD	I realised it. Kerry sent me an email saying deadline,	
183		deadline ... Monday	
184	MC	[ Yeah	
185	CS	[ Does that .. does that mean that we can still once	
186		it's gone in on Monday have we still got time to do	
187		another [ final edit through	
188	MC	[ no	
189	MC	No, that's it	
190	SD	Ok .. Aemh .. I am away next weekend but I come	
191		back on Sunday .. aemh do you want me to read it	
192		all through just to do final edits and things	
193	MC	Aemh .. I don't know that there'd be time Sarah, so	
194		whatever things you want me to include you are hav-	
195		ing to send by the end of .. today, really.	
196	SD	Oh, no no I have said it wouldn't want to include ..	
197		what I meant was once you have got a final draft ..	
198		completely .. you want me to just read it through for	
199		like edits, cause you might have got bored by then.	
200	MC	There isn't enough time. I think I am going to be up	
201		to the wire .. doing the aeh .. you know (inaudible) ..	
202		crossing the Ts and dotting the Is	
203	SD	Yeah	
204	MC	So .. sorry.	
205	SD	No, no that's alright. That's fine. Only if you wanted	
206		me to.	
207	MC	Ok	
208	SH	Alright.	
209	MC	I'll be off	Picking up bag,
210	SH	Yeah, that's alright.	turning towards
211	SD	See you later	door
212	SH	(inaudible)	
213	MC	MC: (inaudible)	Turned away from
214	SH	SH: So we shouldn't (inaudible) .. Yeah	screen




Maria leaves the MRL and Gerald enters. Gerald walks past, glancing at the screen and then continues to inside the main lab.



Time	15:21:28		
Room	MRL	1.2a	
People	SH, MC, GC	SD	
			




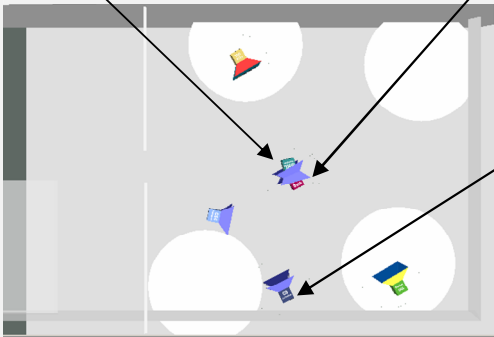
215	SH	Aeh .. it's good (inaudible) audio	
216	SD	I can't .. it's really weird .. I can't hardly hear you. I	
217		can hear the start of each word but not the end of it.	
218	SH	I think it's it must be echo canceller. You have to	
219		really shout down here. I think I have to look at aeh ..	
220		settings	
221	SD	Yeah, I mean when Maria was talking then I could	
222		hardly hear what she was saying	
223	SH	Yeah, yeah	
224	SD	I think she was saying, well tell me if I am right, I	
225		think she was saying she is going to need to keep	
226		dotting the Is and Ts so she won't have time to send	
227		it but I can't I couldn't really tell.	
228	SH	No, she was saying that, [ yes	
229	SD	[ She was saying that ok I wasn't sure I was really	
230		desperately trying to listen but	
231	SH	No, she was basically saying she probably (inaudi-	
232		ble) won't send you anything for editing	
233	SD	I can't. Sorry I can't hear you now. She was basically	
234		saying ...?	
235	SH	She was saying that she will probably not send you	
236		anything .. on [ Sunday.	
237	SD	[ For the final edit. Oh, that's fine. That's good. I	
238		don't have to do it on Sunday [ (laughing).	

After getting up Gemma starts moving the C9 MRACell over towards the home position of the 1.2a MRACell.

Time	15:22:14		
Room	MRL	1.2a	C9
People	SH	SD	GA
			

239	SH	[ Yeah, no absolutely .. Sunday is free now	Typing on keyboard
240	SD	Yeah	
241	SH	Yeah (laughing)	
242	SD	I have sent all my bits .. [ in.	
243	SH	[Ahh, that's good, that's alright. [ Yeah	
244	SD	[ Yeah,	
245	SH	Yeah, what time is it now?	
246	SD	Aeh .. I think it's about .. I just check wait a second ..	
247		I think it's about quarter past or twenty past three.	
248	SH	Ah	
249	SD	Oh, the reason I was asking you when you were re-	
250		cording till it's just that I gotta phone the bank and I	
251		didn't want that recorded	
252	SH	Oh, ok, yeah, yeah, yeah (laughing). I understand	
253	SD	Oh and remind me I have got one, a couple of sen-	
254		tences I need you to edit out.	
255	SH	OK (laughing). When is that? Today?	
256	SD	Yeah	
257	SH	.. How am I gonna do that?	
258	SD	Can you not do that?	
259	SH	Oh, I am sure I can. I mean I [was	

After moving the C9 MRACell, Gemma puts down the JS and gets back to her desk.



Time		15:23:01	
Room	MRI	1 2a	C9
People	SH	SD	GA
			
			

260	SD	[You just don't use or you just don't .. use them	
261	SH	Ok, yeah, we can talk about that off line then	
263	SD	Yeah.	
264	SH	Yeah	
265	SD	But just remind me in case I forget to tell you and	
266		then suddenly you do a presentation and I go	
267		huuuugh (laughing)	



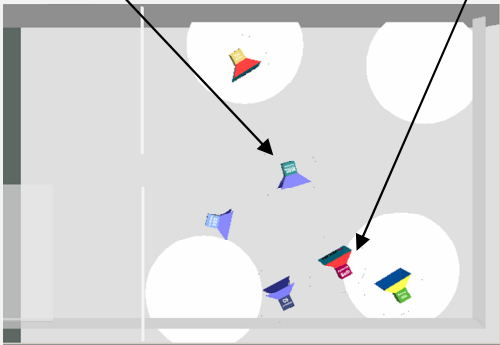
268	SH	(laughing) That's right. I would not do that anyway.	
269	SD	No, I think .. I think you'd realise but yeah	
270	SH	I am not really (inaudible) looking at what happens in	
271		people's offices.. [ (inaudible)	
272	SD	[ No, it's during an interaction though	
273	SH	Yeah	
274	SD	Yeah, so it's during an interaction	
275	SH	Oh it is? [ Alright	
276	SD	[ Yeah	
277	SH	Mmh, interesting (laughing)	
278	SD	Not that exciting it's quite boring but it's just probably	
279		not a good idea to have it on a presentation, that's	
280		all.	
281	SH	Ok, cool	
282	SD	It's like .. it's like, but it is funny, because when I	
283		have been like, you know, you use the phone you	
284		don't think about it, but I am suddenly thinking, you	
285		know, there is issues like for example if you mmh .. I	
286		mean, I know you mainly have got the data but it is	
287		just, if other people could get hold of the data, if you	
288		are for example on the phone and you are ... be-	
289		cause I was going to phone the bank and then I	
290		thought oh, actually you have to be a bit careful with	
291		things like that because you might read out your	
292		numbers and stuff.	
293	SH	Yeah	
294	SD	And even though I know (inaudible) you have got the	
295		data, what happens if somebody in your office .. you	
296		know .. not somebody in your office but somebody	
297		got into your office and got the tapes and they know	
298		all your bank details, you know, details	
299	SH	[Yeah	
300	SD	[You sort of think	
301	SH	I mean, I mean that is .. that is very unlikely because	
302		you would have to break (inaudible) building (inaudi-	
303		ble) and then in the office and [ then into the	
304		cupboard	
305	SD	[ Yeah	
306	SH	But I mean you are right, I mean [ (inaudible)	
307	SD	Yes, but you have to give your pin numbers and	
308		things you see	
309	SH	Yeah, yeah I know [ (inaudible)	
310	SD	[ So actually, yeah, so for just things like that and	
311		there is nothing else that's really, I have really	
312		thought about, everything else has been just warning	
313		other people. But the only thing I did think is if you	
314		are phoning the bank or you are giving out pin num-	
315		bers or some like really personal details you	
316		probably wouldn't want it recorded even though it	
317		wouldn't necessarily be used, it would still be on the	
318		tape.	
319	SH	Yeah. You could always of course aeh pull the plug.	
320	SD	Yeah, I did think about doing that but then just	
321		thought ahh I'll just wait until you have finished re-	
322		recording. Yeah. [ That's fine.	
323	SH	[ It won't be much longer now	
324	SD	No, no, there is no rush (laughing)	
325	SH	(Laughing) Cool.	
326	SD	Right, I shall leave you to it and I'll speak to you a lit-	Waving
327		tle bit later.	

328	SH	Yeah, I'll speak to you later, Sarah, [ bye.	Waving
329	SD	[ Bye.	

Sam turns round and walks in direction of door. Turns around again towards the library and disappears from camera view. Sarah starts pulling the 1.2a MRACell back, away from the MRL MRACell.

Time	15:25:08		
Room	MRL	1.2a	C9
People	SH	SD	
<div>   </div>			

When close to the Bartlett MRACell, Sarah stops and sets her MRACell to red (private state) and puts down the joystick. The MRL MRACell has remained in position.

Time	15:25:32		
Room	MRL	1.2a	
People	SH, MC	SD	
<div>   </div>			
			

### 11.2.3.g Vignette 8 – The Birthday Cake


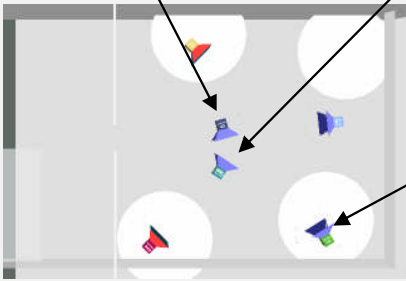
Date	Start time	Duration
19/10/2004	14:51:10	10 min 42 sec

#### Context

It is Thomas' (TA) birthday at the Bartlett MRACell and someone has brought in a cake to celebrate the occasion. Thomas re-configures the MRA to have a 'virtual birthday', while not explicitly telling others in the MRA. After a brief 'happy birthday' song by Fran (FC), Michael (MC), Christian (CD), Serena (SO) and Collin (CB), the cake is distributed. Collin and Michael decide to 'show' the cake (very large in camera view) to the 'recording' and to Sam (SH) at the open MRACell of C9. Although Samir (SW) is present there, no conversation results from this interaction. Collin and Michael then decide to move on to visit the MRACell, where they show the cake again. Rick (RL), who is just passing through, also is not being involved in a conversation.


#### Vignette

The C9 and MRL MRACells are arranged in an open triangle, facing each other. Sam can be seen at his desk in C9, Samir is present but not in camera view. The Bartlett and C54 MRACells are set back but are open. Thomas can be seen dealing with the birthday cake in the Bartlett MRACell while others can be heard in the background. There is a meeting between Rebecca and Kate in C54. The 127C MRACell and the 1.2a MRACell are set back and closed. There is a meeting in 127C between Scott and a visitor. Nobody appears in camera view in the 1.2a MRACell. Only the C9, MRL and Bartlett MRACell play a part in this vignette. Thomas enters the Bartlett MRACell and starts unpacking the plastic bag that contains the birthday cake.

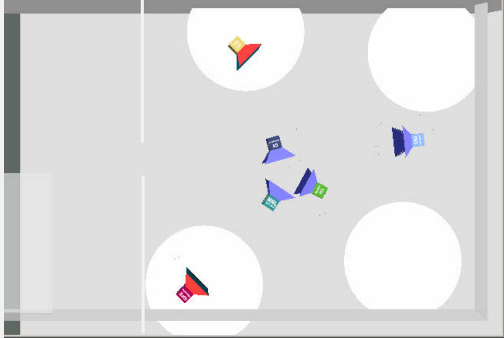
Time	14:51:10		
Room	C9	MRL	Bartlett
People	SH, SW		TA
			
			

1	TA	Oh wow .... Thank you	Looks at screen
2	??	(inaudible)	
3	TA	Oh, yes, let's set off the fire alarm straight [ away.	
4	FA	[ (laughing) By the way, by the way aeh ... Sam is	
5		recording ... [(laughing)	
6	TA	[ Sam is recording?	
7	FA	(inaudible)	
8	TA	Sam! ... We are now to set off the fire alarm.	
9	??	(inaudible)	

Thomas walks around the meeting table and approaches the screen, where he grabs hold of the JS located very close to the camera. His face appears very large on the video.

Time	14:51:35		
Room	C9	MRL	Bartlett
People	SH, SW		TA, FC, FA
			

Thomas then reconfigures the MRA so that the Bartlett MRACell is located near to the MRL and C9 MRACells, facing them both. These three MRACells are now set up in a triangle.


		
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He goes back to the meeting table.

10	TA	Aehaeh ... Virtual birthday party	Facing the desk area
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Sam looks up and keeps looking at the screen for about 7 seconds, while Thomas is cutting the cake at the Bartlett meeting table. Sam would have had a good view of that activity and the two cells were in audio range of each other. However, no conversation is initiated.



Time	14:51:47		
Room	C9	MRL	Bartlett
People	SH		TA
			

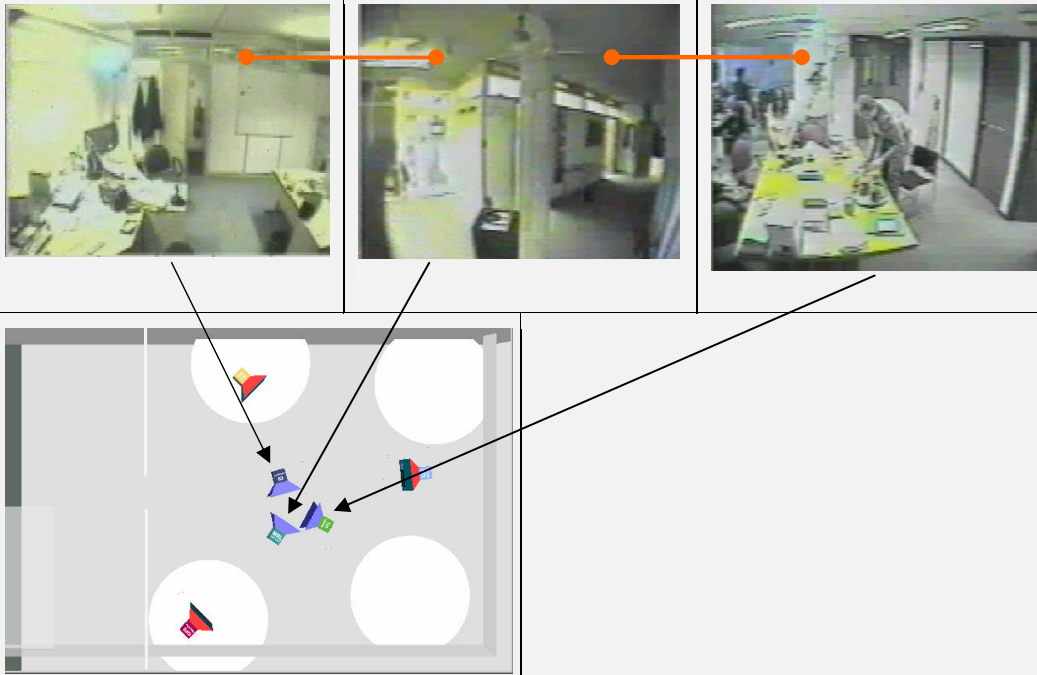
The conversation around the Bartlett meeting table continues for a while. People talk about the cake, candles and setting off the fire alarm but audio quality is rather poor as this conversation is taking place between people in the physical part of the Bartlett MRACell rather than across the MRA. The meetings in 127C and C54 end and Kate sets her MRACell to private. The C9, MRL and Bartlett MRACell are all open and still arranged in a tight triangle in the middle of the virtual space. A number of people pass through the MRL MRACell and glance at the screen, which has the other two MRACells in good view and is in audio range. The preparations around the meeting table at the Bartlett continue.

11	FC	Now, we can show Holger virtual cake. Ha, ha, ha.	
12	TA	... Eat this virtual cake.	

Fran is looking on while Thomas continues cutting the cake. People start assembling and someone is taking a picture of Thomas and Serena posing behind the cake. Sam looks up at the screen again, gets up from his desk and asks Samir, whether he wants anything from the shop. He then leaves. Nobody is in camera view in C9 from then on. More people are then starting to assemble around the meeting room table in the Bartlett MRACell.

13	TA	Right .. we have got serviettes, is the next question.	Serena places box of tissues on table
14	FC	We haven't got serviettes	
15	CD	(inaudible) we don't have. But we have .. white paper	
16		(laughing)	
17	TA	(laughing)	
18	??	White paper?	
19	TA	..... Alright? ..... OK.	
20	ALL	Happy birthday to you, happy birthday to you, happy birthday dear .. Thomas (inaudible), happy birthday to you.	
21			
22			
23	CM	Haaaaay!	

Slices of the cake are shared out and people stand around the meeting room table eating. The conversation continues but again the audio quality on tape and MASSIVE recording is too poor for transcription.

Time	15:00:03		
Room	C9	MRL	Bartlett
People			TA, FC, OS
			


24	TA	Michael, do you want cake?	Michael is off camera
25	MC	Aehm, no (inaudible)... Oh you know,	
26		why not? Yes, I'll have some.	
27	FA	(inaudible)	In background

Collin enters the Bartlett MRACell from his office, which is directly adjacent and waits near the meeting room table. Collin receives a slice of cake from Thomas.

28	MC	Ahh, it's not chocolate cake	
29	CB	(inaudible) chocolate one?	
30	MC	Ohh (inaudible) spongy one.	

Michael walks past the front of the screen and stops at the table with his back to the camera. Collin stands back a little, with the cake in his hand looking at the screen. Then he comes over to show the cake to the camera.



Time	15:01:07		
Room	C9	MRL	Bartlett
People			CB, MC, TA, FA
			

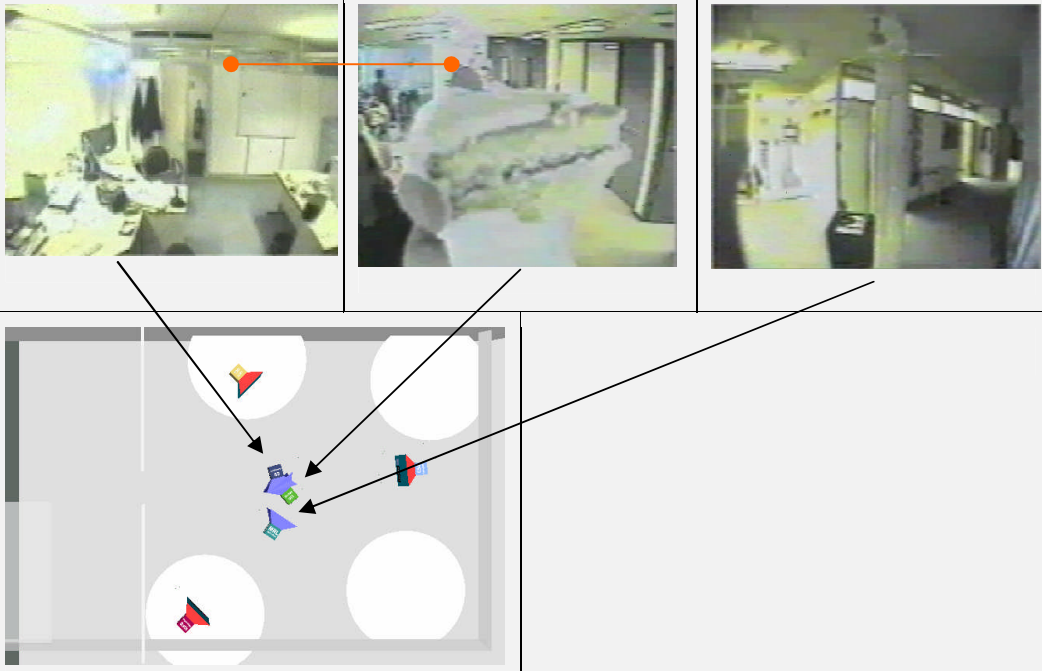
31	CB	Ooohhh ....	Pointing cake
32	MC	(inaudible) make sure I have got a slice (inaudible) on a	into camera
33		tour .....Yeeess ...ah you better get go close to some-	
34		one and show it off	
35	BC	Ooohhh.	Moving cake
			around

Michael gets hold of the joystick and starts moving closer to the C9 MRACell.

36	MC	Just show you.	
----	----	----------------	--

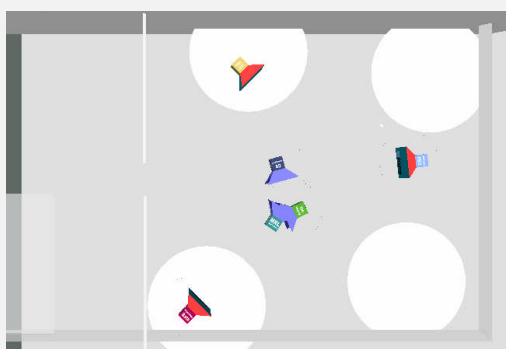
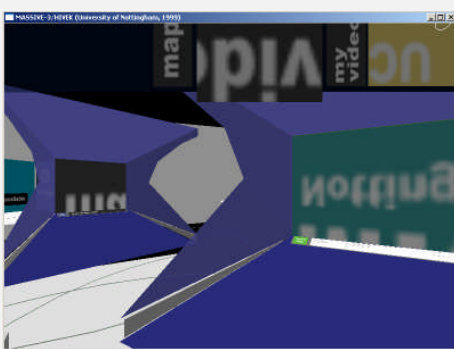
Michael arrives at the C9 MRACell where no one is in camera view while Samir is actually present in the office. Typing can be heard in the background.

37	MC	Yeah, show his empty chair. He's recording it.	
38	CB	I will hold it there for several minutes	

Time	15:01:28		
Room	C9	Bartlett	MRL
People		MC, CB	
			


39	MC	Shall I go and find somebody else?	
40	CB	Oouuuuh	

Michael is pulling back from C9, turning and then orienting the Bartlett MRACell towards the MRL MRACell. The Bartlett MRACell is placed in front of the MRL MRACell at an angle. This position means that video of the Bartlett MRACell filled about one sixth of the screen estate of the MRL MRACell. The C9 MRACell could be seen in the background with its video stream filling about one 12<sup>th</sup> of the screen estate.

Time	15:01:45		
<div></div> <div></div>			


41	MC	Oh, look. There is someone to show it to.	
----	----	---	--

Rick enters the MRL MRACell through the main glass door.

Time	15:01:45		
Room	C9	Bartlett	MRL
People		CB, MC	RL
			

42	CB	Ooohh .... Ooohhh	
43	FC	Yeah show him the cake	
44	BC	[Ooohhhh	

He is looking at the screen, hesitates briefly, but then walks past.

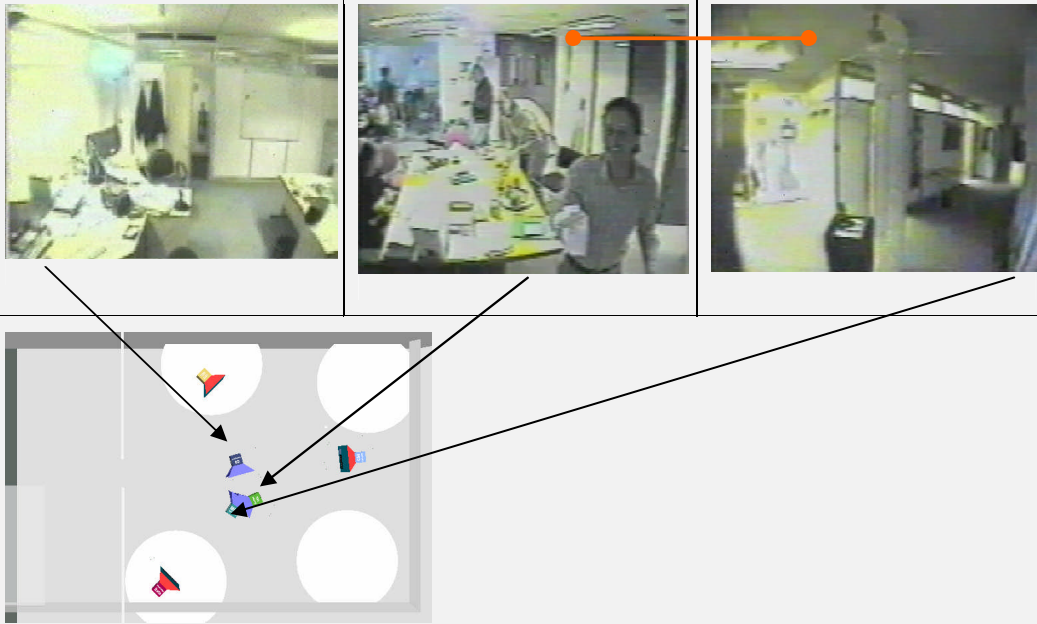
Time	15:01:49		
Room	C9	Bartlett	MRL
People		CB, MC	RL
			

45	MC	[Ooohhh, he's ignored it	
46	FC	Aoh	

Michael walks away from the screen and sits back down at the meeting table.

47	CB	Look at the giant cake	Cake into camera
48	MC	(laughing)	
49	CD	(laughing)	
50	CB	Hmmm [ mhhhhh	
51	MC	[ Hmmmh	
52	All	(laughing)	

Collin then moves back, cake still in hand and looking at the screen.

Time	15:01:52		
Room	C9	Bartlett	MRL
People		MC, FA, CD, TA, CB	
<div></div>			

Collin moves back near the table and then returns to this office. Michael, Christian, Thomas and Fiona are around the table eating their cake. Thomas leaves the Bartlett MRACell through the double door in camera view.

#### 11.2.4 Video DVD

The DVD attached to the back cover contains the following accompanying video clips:

*11.2.4.a Study1: Presenting in Mixed Reality*

*11.2.4.b MRA Prototyping*

*11.2.4.c Mixed Reality Architecture*



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